SURTSEY RESEARCH PROGRESS REPORT

VI

THE SURTSEY RESEARCH SOCIETY · REYKJAVÍK, APRIL 1972

SURTSEY RESEARCH PROGRESS REPORT

VI

PRIMARILY

1969 AND 1970 FIELD SEASONS

SURTSEYJARFÉLAGID

THE SURTSEY RESEARCH SOCIETY

REYKJAVIK, APRIL 1972

PRINTED BY SETBERG · REYKJAVIK · ICELAND

Index

Introduction

An historic account of the volcanic island Surtsey, which was formed by a submarine eruption on the 14th of November, 1963, approximately 20 miles off the south coast of Iceland, should no longer be necessary. It has become a well known fact. Also, the extensive scientific work that started as soon as the island was created, should be familiar, at least to those who have received the Surtsey Research Progress Reports.

This report is the sixth in the series published by the Surtsey Research Society. Previous reports have covered one field season each. The following report has been changed to cover the field seasons 1969 and 1970, and even with a touch of 1971.

The overall development of Surtsey has slowed down. Although the island changes from year to year with the sea taking off a good slice and geological processes continuing, this has reached a stage of a more stable and gradual change than originally. The same holds true in the field of biology. Life has established itself on the island and on its socle, its future seems certain and its development is stable. In several fields of science it has therefore not been found necessary any longer to undertake yearly investigations. Every second summer is in most cases sufficient and even longer periods.

Thus, the plan is to publish the progress reports every second year and include all reports available at the time of publication, regardless of the field season. Continuity will, on the other hand, be stressed as previously.

As before, the scientific work on Surtsey has been supported from several sources. The Icelandic Government, research institutions, the Icelandic Coast Guard, and others in this country, have given support, either with financial appropriations, time for scientific personnel, facilities or transportation. Financial support has also been received, as previously, from various foreign agencies, especially the U.S. Atomic Energy Commission, and the Bauer Scientific Trust. All of this is highly appreciated. Also, one must have in mind that the scientific work on Surtsey would not have been possible without the unselfish work of several scientists from Iceland and from abroad and the excellent cooperation that exists.

Surtsey has become a reality and although the sea cuts a slice from the island every year, it will most likely stand for centuries. Fortunately, scientific studies were started on the island as soon as possible. This work has already led to valuable scientific understanding. Hopefully it will be possible to continue this work for years to come. The opportunity is unique. With mankind increasingly needing a better understanding of its environmental development, it should be explored to the utmost.

For The Surtsey Research Society,

Steingrímur Hermannsson
Chairman

BIOLOGY

Moss on Surtsey, Summer 1969

By
ÁGÚST H. BJARNASON and
STURLA FRIDRIKSSON*
* The Agricultural Research Institute, Reykjavík, Iceland

It was first in the middle of August 1969 that moss really became conspicuous on Surtsey. During the first part of the summer some small moss patches were admittedly to be seen, but about and after mid-August large areas became covered with it. It is possible that the frequent rains caused this enormous increase in development.

The following moss species were found on Surtsey. These were analysed by Bergthór Jóhannsson.

1) *Bryum argentum*
2) *Bryum caespiticium*
3) *Bryum capillare*
4) *Funaria hygrometrica*
5) *Leptobryum pyriforme*
6) *Pogonatum urnigerum*
7) *Racomitrium canescens.*

The areas in which moss was found were in the following quadrats:

1) *HI 7–10 and J 10* – This area is on the slopes of the crater Surtur II. In the lava round the crater there is still an emission of heat and steam. Most of the lava, or about 80%, is sand-covered, and there the moss is most abundant. It grows there in many places in large patches with a cover of about 40–50%. On the lava slopes of the outer side of the crater the moss is scanty and the cover very small. There one specimen of *Pogonatum urnigerum* was discovered.

2) *MN 13 – OPQ 12–14* – Area stretching from the crater Surtur I for about 500 m in a SSE direction. This part of the lava is not sand covered except in small caverns and hollows. Some moss grows on the lava but especially in the sand hollows. Although it is widespread, it nowhere forms patches bigger than the palm of the hand. The total cover is less than 5%. There is a slight emission of heat and steam in that part of the lava. This however does not always effect the distribution of the moss. Some of the *Funaria hygrometrica* which grew there had spore capsules.

3) *M 3* – In this quadrat *Funaria hygrometrica* was growing on the sand, forming a patch of about 15x15 cm. There is no heat in the area.

4) *H 13–14* – Moss was found growing in and near the Strompur lava crater and near a small emission hole up on Vestri Bunki. Where the moss was found growing the craters are very sandy and there is great emission of heat and steam.

5) and 6) *J 13-K and K 12* – In this area the mosses grow in sandy craters on the slope north of Surtur I. There is great emission of heat and steam up through the lava and the moss is found mainly on ground over which the steam drifts. The cover is about 5–10%.

7) *KL 15* – In these quadrats the moss grows in the sand almost exclusively in small caverns. This place is close to one of the plastic containers set up for trapping fresh-water microorganisms, around which some algae are growing as well as four plants of *Cochlearia officinalis*. It is probable that the moss is in this particular place because of these unnatural moisture conditions. There is no emission of heat or steam. The cover in the caverns is in many places 5–10%.

8) *L 12* – This quadrat is on the cinder slopes of Surtur I. The moss grows in isolated patches over much of the lava, but the cover is nowhere extensive. Although there is heat and steam emission very nearby, it in all probability has no effect on the moss in this quadrat.

It is clear from this survey that the moss growth areas may be divided into the following classes:

A) *Bare lava,* where there is *no* effect from heat and steam emission. Hitherto, the moss has nowhere formed large or dense areas of growth in this substrate (e.g., L 12 and MN 13 – OPQ 12–14).

B) *Bare lava,* where there *is* an effect from heat and steam emission. In this substrate the temperature does not seem to effect the distribution of moss (e.g. H 13–14).

C) *Lava hollows and caverns,* in which the sand has accumulated but where the lava is otherwise relatively bare. In this substrate there is no heat or steam emission and no movement of sand where moisture is most abundant. The areas grown by moss are small and scattered. On the whole, the total cover is small.

D) *Sandy lava,* where there is much heat and steam emission. It is here that the moss zones are most extensive and the cover densest (e.g., HI 7–10, J 10, and H 13–14).

It is almost impossible to describe the distribution of each individual species. The most common is *Funaria hygrometrica,* which grows almost everywhere. Then come *Bryum argenteum* and *Leptobryum pyriforme. Racomitrium canescens* is not very common and only found on bare lava. *Pogonatum urnigerum* was found only in one place in the middle of the cinder slopes of Surtur II.

Moss is most common in areas where there is heat and steam emission. The vapour stabilizes the sand and keeps a constant moisture in the substrate. It is thus far more probable that the moisture in the steam has a much bigger effect than the heat.

Microbiological Observations on Surtsey, 1970

By

THOMAS D. BROCK

Department of Bacteriology, University of Wisconsin, Madison, Wisconsin 53706

During the 1970 NASA expedition to Iceland and Surtsey I was able to continue my microbiological studies of Surtsey, following up on previous work done in 1965 and 1966. My previous two visits to Surtsey coincided with the Syrtlingur and Jólnir eruptions and most of the potential sites for biological development were being covered with volcanic ash. Now that eruptions have ceased and the habitats are more stable, biological studies can be carried out. The distribution of life seems closely associated with the availability of moisture, either as steam condensation from fumaroles or near the sea in lava crevices where higher humidities would be expected. Two kinds of microbiological studies were done: 1) Observations on the relative importance of blue-green algae versus higher plants (mosses and vascular plants) as primary colonizers; 2) The distribution of bacteria in terrestrial habitats. The conclusions from these studies can be simply stated: 1) Blue-green algae are *not* the primary colonizers of Surtsey, except in thermal areas where higher plants do not grow; and 2) Bacteria are found in terrestrial environments in the rhizosphere of plants, both mosses and vascular plants, and also on ash near blue-green algae and in fumaroles, but not in ash away from plants and fumaroles.

METHODS

The visit was made on 26 June 1970. Samples of soil, plants, and algae were taken in various parts of the island. For quantative study of relative importance of blue-green algae and higher plants, cores of green material were taken in a number of locations using a # 4 cork borer. Soil pH values were measured the same day using an Orion battery-operated pH meter after making a 1:1 mixture of soil and deionized water. Temperatures were measured with a Yellow Springs Instrument Co. thermistor. Preliminary microscopy was done the same day using a Carl Zeiss phase microscope and detailed microscopy was done 6 July 1970 using a Zeiss fluorescence microscope. With the latter, bacteria were sought upon soil particles and plant roots using acridine orange as a fluorochrome and a vertical illuminator, thus permitting examination of opaque surfaces. Algae were observed using the Zeiss phase contrast microscope.

RESULTS AND DISCUSSION

1. Are blue-green algae the primary colonizers of Surtsey?

In a number of areas on Surtsey, visibly green patches were taken and examined microscopically for the presence of blue-green algae and mosses. Such patches were mainly found where moisture levels were high, either in steam condensate from fumaroles or in crevices of lava rocks. In regions very near fumaroles, the temperature was high, 30—60°C, and in these areas blue-green algae were found. Thermal habitats of this type are rare on Surtsey, and studies of the algae present were carried out by R. W. Castenholz, University of Oregon, Eugene, Oregon, who reports (personal communication) that the cosmopolitan thermal alga *Mastigocladus laminosus* was present. Most habitats with green patches where condensing steam was present are not thermal, and temperatures around 25°C or less were measured. The present work concentrated on these non-thermal areas, which were mainly around the newest crater of Surtur II in the southeast quadrant of the island. The data are presented in Table 1. The soil pH measured on several samples was 7.8—7.9, which is in an appropriate range for the growth of blue-green algae, yet no blue-green algae were found. I conclude, therefore, that blue-green algae are not the primary colonizers of non-thermal habitats on Surtsey. In the moister areas mosses were found and in drier habitats vascular plants were found. These observations suggest that vascular plants and mosses are the primary colonizers of non-thermal habitats, and only in thermal habitats are blue-green algae present.

Although these observations may seem at variance with those of Schwabe (G. H. Schwabe, 1970, On the algal settlement in craters on Surtsey during Summer 1968, *Surtsey Research Progress Report V,* 68—69; Schwabe, G. H., 1969, Pioniere der Besiedlung auf Surtsey, *Umschau in Wissenschaft un Technik* 2, 51—52; Schwabe, G. H. 1969, Ökogenese auf vulkanischem Subsrat, Intern. Symposium für Vegetationskunde,

TABLE 1

Search for blue-green algae in green patches in non-thermal areas where condensing steam was present

Sample	Moss	Blue-green algae
Near Surtur II		
878	Present	Absent
933	Present	Absent
869	Present	Absent
930	Present	Absent
916	Present	Absent
963	Present	Absent
971	Present	Absent
964	Present	Absent
924	Present	Absent
936	Present	Absent
960	Present	Absent
954	Present	Absent
Near Surtur I		
863	Present	Absent
912	Present	Absent

TABLE 2

Bacteria associated with volcanic ash and plants

Sample	Material	Observations
22-1	Ash 6 cm from *Minuartia peploides* pH 6.4	No bacteria
23-1	Ash attached to *M. peploides* *p*H 6.85	Many small rods, few actinomycete hyphae
23-1	Root hairs of *M. peploides*	Few small rods
23-3	Ash in fumarole with alga *Mastigcladus laminosus,* 60°C, pH 7.8	Many small rods, some in microcolonies
24-1	Ash in fumarole with *M. laminosus* 40—50°C, pH 7.8	Many small rods, some in microcolonies
24-2	Ash in fumarole no algae, 90°C, pH 7.9	Frequent small rods, some in microcolonies
24-4	Ash in fumarole, no algae, 55°C, pH 5.1	No bacteria
24-6	Ash in fumarole, no algae, 39°C, pH 5.1	No bacteria
25-1	Ash in condensing steam near Surtur II, 25°C, pH 7.9	Many small rods, many in microcolonies
26-1	Ash in fumarole, 95°C, pH 7.5	Frequent small rods
26-2	Ash in fumarole, 74°C, pH 7.9	Frequent small rods
26-3	Ash in tufa cliff away from fumaroles, air temperature, pH 7.3	Frequent small rods, some in microcolonies
26-4	Moss rhizoids	Many actinomycete hyphae
26-4	Ash near moss rhizoids	No bacteria
26-5	Roots of *Minuartia peploides*	Many small bacteria
26-5	Ash near *M. peploides* roots	No bacteria
27-2	Ash from tufa cliff near hut, air temperature, pH 6.65	No bacteria

Assessment based on fluorescence microscopy after acridine orange staining.

Rinteln; Schwabe, G. H., Blue-green algae as pioneers on post volcanic substrate (Surtsey/Iceland), unpublished manuscript, Plön, January 1970), examination of Schwabe's papers shows that he assessed blue-green algal development by enrichment culture techniques, which are excellent for floristic surveys aimed at detecting organisms present even in small amounts, but do not provide any estimate of quantitative abundance. Direct microscopy, used in the present study, will miss rare organisms but will give a good estimate of the quantitative importance of dominants. Thus the fact that I have not detected blue-green algae in my cores does not mean that they are not present, but only that they are rare. Blue-green algae are hence probably not of any great ecological significance in contributing organic matter for soil formation and for the development of heterotrophic microorganisms and higher levels in food chains, whereas mosses and vascular plants clearly are.

2. Bacteria in terrestrial habitats on Surtsey. The use of the fluorescence microscope with acridine orange staining permits a direct examination for the presence of bacteria on opaque surfaces. Samples of volcanic ash, mosses, and vascular plants were studied. Some samples of ash were collected from around plant roots and others were collected at sites quite distant from plant roots. The results, given in Table 2, show that bacteria are widely but not universally distributed in terrestrial environments on Surtsey. Virtually every plant root or rhizoid examined had a high bacterical population, as would be expected since it is well know that roots and rhizoids excrete organic materials upon which bacteria can grow. Bacteria were also found in large numbers in ash near fumaroles, even ones of quite high temperature (90—95°C), although not in ones where the ash is acidic. Some samples of ash collected near to but not attached to roots or rhizoids were devoid of bacteria. Thus it seems that bacteria develop in large numbers where appropriate energy sources are available (probably organic materials in plant rhizospheres and inorganic reduced compounds in fumaroles). Although the sources of bacterical inocula are unknown, it seems reasonable that those bacteria associated with plants were brought to Surtsey attached to the plant disseminules. Those bacteria associated with fumaroles were probably dispersed through the air, either free or attached to particles.

The assistance of W. N. Doemel in some of the sampling is appreciated. This work was supported in part by a research grant from the National Science Foundation (GB-19138). The visit to Surtsey took place during my participation in a field trip sponsored by the National Aeronautics and Space Administration.

The Occurrence of the Thermophilic Blue-green Alga, Mastigocladus laminosus, on Surtsey in 1970

By
RICHARD W. CASTENHOLZ
Department of Biology, University of Oregon, Eugene, Oregon, U.S.A.

INTRODUCTION

Although several species of blue-green algae and other algae have been reported from moist areas surrounding steam vents on Surtsey, none of these appear to be true thermophiles exhibiting growth optima above 45°C (Schwabe, 1970a, 1970b; Behre & Schwabe, 1969). The volcanic island of Surtsey was first formed in late 1963 off the south coast of Iceland.

Mastigocladus laminosus (Ag.) Cohn is a cosmopolitan thermophilic blue-green alga (Schwabe, 1960) and its various forms are very common in almost all of the hot springs and steam vents of Iceland which have a neutral to alkaline pH and are below a temperature of about 63—64°C (Castenholz, 1969a). Two very distinct forms are common in Icelandic hot water. One is a seldom-branching trichome which grows at temperatures constantly as high as 63—64°C, thus representing the upper limit photosynthetic blue-green alga of Iceland. The other is the typical branching form which does not grow above about 57°C (Castenholz, 1969a).

On June 26, 1970 I examined several of the steam vents of Surtsey, particularly those near the old (or easternmost) crater. From these I collected presumptive algal specimens in the moist ash which recorded temperatures as high as 65°C. The greatest abundance of steam vents occurred on the inner (southern) slopes of the old crater, on the lava flats on the southeastern side of the crater, and within the north-south fissure created during the 1966—67 eruptions. The major collection stations are numbered on Fig. 1. Almost all collections were examined in the field with a Cooke-McArthur field microscope fitted with a phase contrast system with 400x total magnification. Blue-green algal trichomes were quite abundant in some of the collections, particularly Station 2, and most of the material from the thermal collections looked like the high-temperature form of *Mastigocladus*. The purpose of this short study was to prove that this material was indeed *Mastigocladus* and that it was capable of growth at various temperatures above 45°C

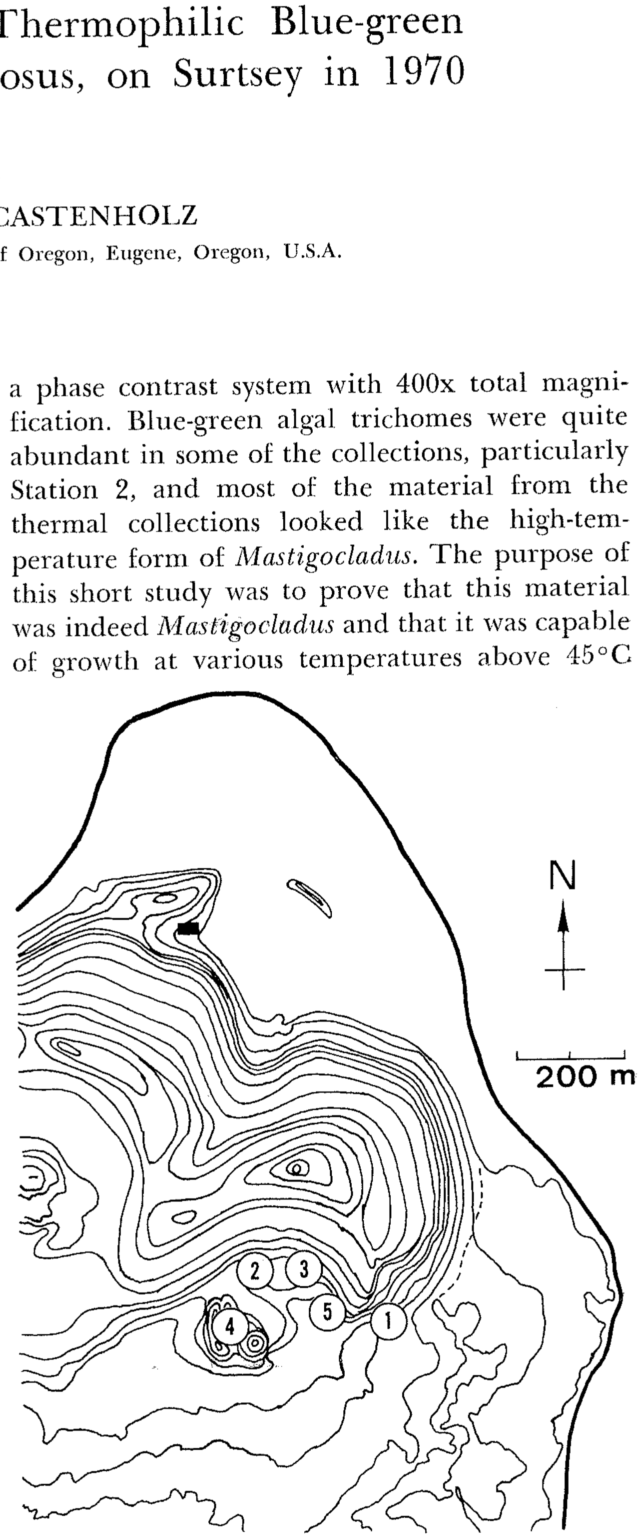


Fig. 1. Map of the northeastern portion of Surtsey indicating collection stations in the eastern crater region.

and even at 60°C. For this, culture isolations and growth experiments in the laboratory were carried out.

Some of the hot moist areas around steam vents were a faint green color due to the density of blue-green algae. Mosses and other algae were also restricted to moist areas near steam vents but at lower temperatures and in more protected areas such as the fissure of the 1966—67 eruptions (Station 4, Fig.1).

MATERIALS AND METHODS

The collections were made and treated as follows. Sterile vials were used throughout and forceps were resterilized between collections in the high temperature steam of the vents (> 90°C). The samples containing algal material and moist ash were stored in darkness at between 15° and 25°C for approximately 12 days before culture enrichment and isolation techniques were applied. These conditions of storage have proved quite satisfactory for thermophilic blue-green algae in past work (see Castenholz, 1969b, 1970). Duplicates of some of the samples were preserved with formalin on the collection day.

The culture techniques used for the samples in my laboratory at the University of Oregon were those standardly used for the isolation of *Mastigocladus* (Castenholz, 1969a, 1969b, 1970) except that medium free of combined nitrogen was not required in these cases for the initial enrichment of the organism. The high-temperature forms were sought for, in particular, by the methods used.

(1). Tubes and fasks containing medium *D* were inoculated with samples from 7 of the collections and incubated at 60°C under approximately 2,000 lux *(coolwhite* fluorescent lamps) — continuous light. Similar inoculations were made of all the collections in liquid medium *D* with incubations at 45°C. Some were treated similarly at 30°C.

(2). Inocula from almost all collections and enrichment cultures were also placed or streaked on medium *D* solidified with 1.5% (w/v) agar in 20x150 mm plastic petri plates. Incubations were primarily at 45°C, but some plates were also held at 60°C or 30°C. Individual trichomes which subsequently radiated from inoculum as motile hormogonia or by growth processes were then easily isolated with watch-maker's forceps on small pieces of agar. These were transferred to liquid medium *D* to establish clone cultures.

The decisions as to what forms of *Mastigocladus* were present at the various sites on Surtsey are based primarily on the culture isolations rather than the fresh or preserved collections of ash. The taxonomy of blue-green algae (including *Mastigocladus)* is currently in a confused state, principally because it has traditionally been based solely on morphology, a highly variable criterion in some groups. Thus, clonal culture should be used whenever possible together with collections.

COLLECTIONS (FIG. 1)

S-1: steam vent on flat ground; ash temperature 58—60°C at lip of orifice; slightly green cover — unbranched *Mastigocladus*-like trichomes in clusters on ash particles.

S-2: crescent-shape ridge on crater slopes with vents on and under crest; *a* = east vent, 40—50°C (collection site); *b* = center vents, 35—50°C, pH 7.8 (determined by W. Doemel), slightly green cover of unbranched *Mastigocladus*-like trichomes; *c*=west vents, 45—55°C and 15—20°C.

S-3: on crater slopes, several vents, 45—65°C; no algae found in collection.

S-4: large north-south oriented fissure and crater from 1966—67 eruptions; many steam vents at base and on walls of fissure; *a* = steamy area on top of north end, < 20°C, visible moss cover; *b* = near top of north end, 20—25°C, crevices in rock with moss and algal cover; *c* = wet wall below steam vents near base of fissure, *ca.* 55°C, no visible algal cover, but unbranched *Mastigocladus*-like trichomes in clusters on same ash particles.

S-5: several steam vents on flat lava flow below inner wall of crater; *a* = 45—55°C, unbranched *Mastigocladus*-like trichomes and more typical branching *Mastigocladus* also on ash particles; *b* = 55—65°C, no algae found on particles.

CULTURES

The results of the original culture enrichments in liquid medium *D* at 30°, 45°, and 60° are summarized in Table 1. Most collections incubated at 45°C gave rise to *Mastigocladus* but only the unbranched form. Two of the collections of material made below 25°C did not. Almost all of the collections which gave rise to *Mastigocladus* at 45°C also did so when incubated at 60°C. This again was the unbranched "high-temperature" form. None of the collections gave rise to this form of *Mastigocladus* when incubated at 30°C instead of either of the higher temperatures. Other filamentous and coccoid blue-green algae came up at 30°C in addition to unicellular and

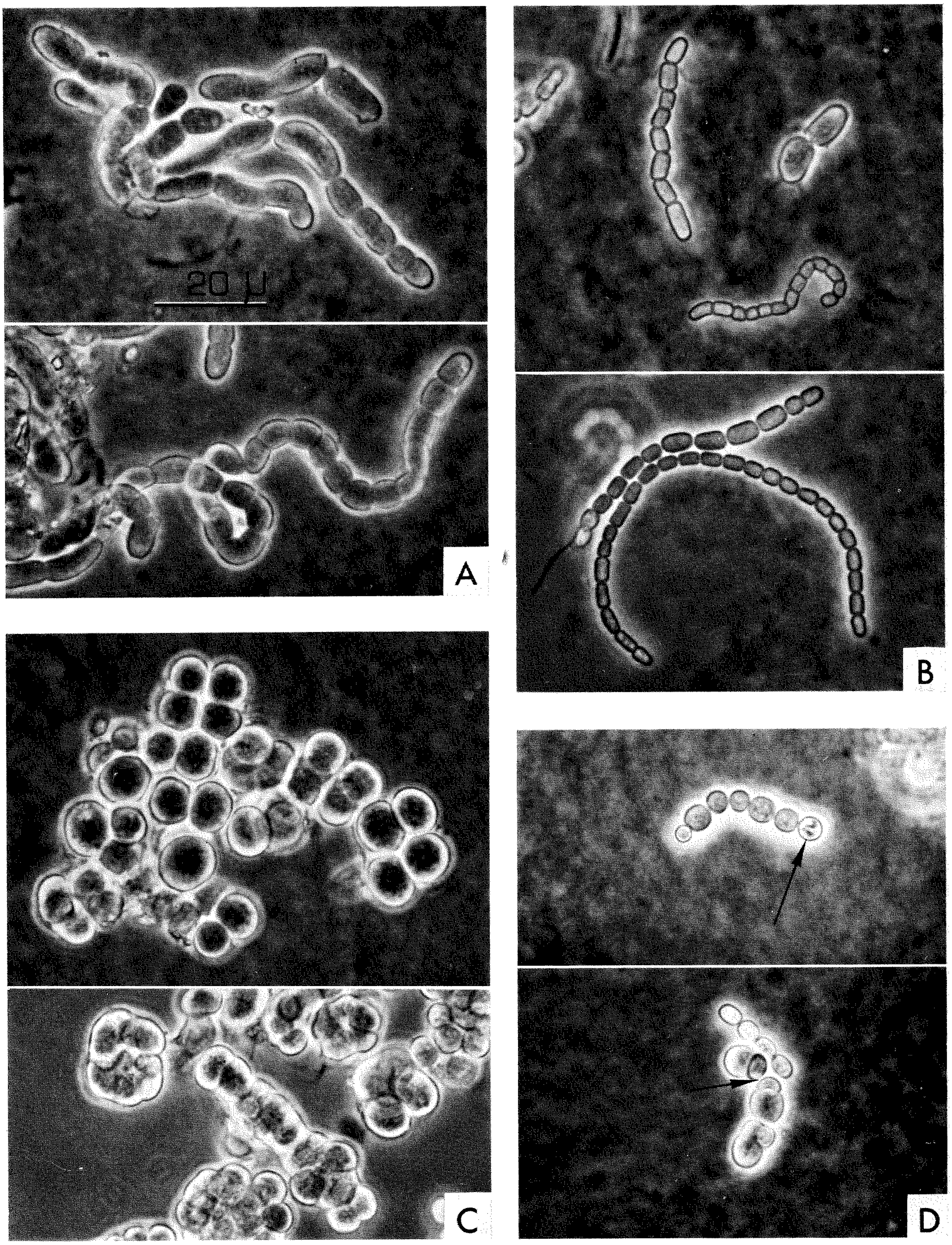


Fig. 2. Culture I-S_2-m Clone 3— the non-branching form of *Mastigocladus*, originally isolated from a 60°C enrichment (collected from station S-2b, 35°–50°C). (A). grown in complete medium at 60°C. (B). grown in complete medium at 45°C. (C). grown in complete medium at 45°C – slow growth conditions. (D). grown in medium lacking combined nitrogen at 45°C; developing heterocysts are indicated.

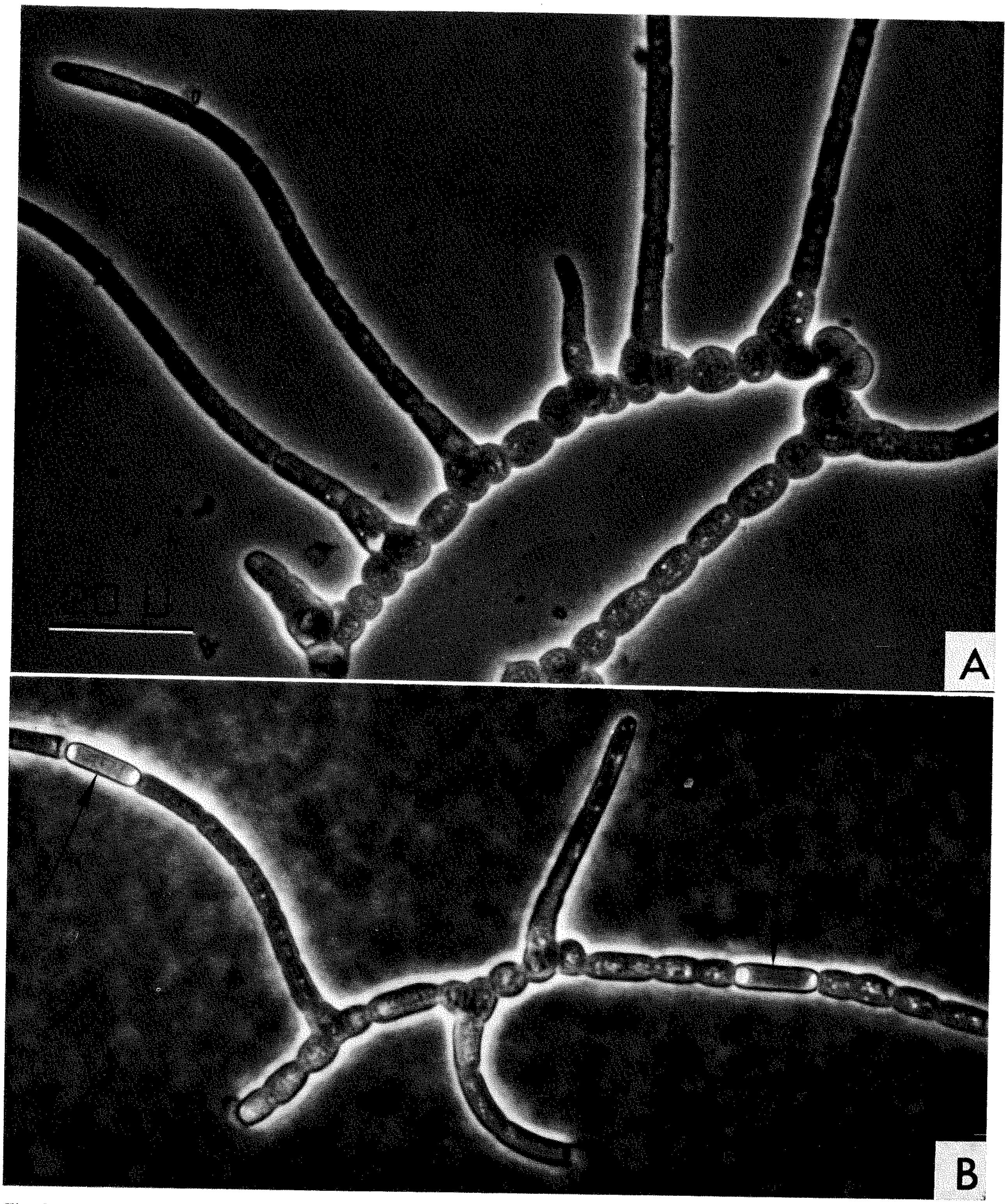


Fig. 3. Culture I-S_5-m Clone 1— the typical branching form of *Mastigocladus,* originally isolated at 30°C (collected from station S-5a, 45—55°C). (A). grown in complete medium at 45°C. (B). grown in medium lacking combined nitrogen at 45°C; heterocysts are indicated.

TABLE 1

Enrichments of Mastigocladus (M = unbranched form; Mt = typical branched form) from samples collected at stations on Surtsey. A = other blue-green and green algae.

Station	30°C	45°C	60°C
S-1 (58-60°C)	—	M	M
S-2a (40-50°C)	—	M	M
S-2b (35-50°C)	A	M	M
S-2c (15-20°C)	A	0	—
S-2c (45-55°C)	A	M	M
S-3 (45-65°C)	0	0	0
S-4a (20°C)	A	M	—
S-4b (20-25°C)	A	0	—
S-4c (55°C)	—	M	M
S-5a (45-55°C)	Mt, A	M	—
S-5b (55-65°C)	—	M	0

TABLE 2

Cultures of Mastigocladus from Surtsey presently maintained at the University of Oregon (November, 1970).

Culture	Clone	Culture Temp. °C	Collection Station	Collection Temp. °C	Notes
I-S_2-m	1	45,60	S-2c	45-55	unbranched "high-temp." form
	2	45,60	S-2a	40-50	" "
	3	45,60	S-2b	35-50	" "
I-S_4-m	1	45,60	S-4c	55	" "
I-S_5-m	1	45	S-5a	45-55	f. *typica*, branching; does not grow above 53°C.

colonial green algae. In one case, however (S-5a), a typical branching form of *Mastigocladus* arose at 30°C. This was later isolated and cloned. The same inoculum gave rise to the unbranched form of *Mastigocladus* at 45°C (Table 1). Many of the enrichments of *Mastigocladus* at 45° and 60°C were subsequently cloned from agar plates by manually removing single trichomes (under a dissecting microscope), then inoculating each into liquid medium in culture tubes. Although several clones of most cultures were successful only those listed in Table 2 have been retained in the culture collection.

The two principal forms of *Mastigocladus laminosus* occurring on Surtsey are illustrated in Fig 2 and 3. The species as interpreted by Fremy (1936) and Schwabe (1960) is highly polymorphic. However, it may be seen that even clonal cell lines are highly plastic in morphology. The growth form depends to a large degree on the environmental conditions in culture and on the age of the culture (Castenholz, 1970, and unpublished data) The complications of morphological variability in *Mastigocladus laminosus* have been most recently discussed by Schwabe (1960) and are also being investigated at present in my laboratory. Any further discussion now, however, would be out of place for the purposes of this report.

The unbranched form (Fig.2) grows well in culture at both 60°C and 45°C; growth is slow, however, at 30°C. The branched form (Fig 3) from Surtsey did not grow at 60°C; even at 55°C no growth was apparent. The upper growth limit in this case appears to be about 53°C. Growth also occurred at 45° and 30°C.

DISCUSSION

The principal result reported here is simply the occurrence of at least two genetic types of *Mastigocladus* on Surtsey, the first report of a truly thermophilic blue-green alga on this new island. The "high-temperature" form, at least, was fairly well distributed around most of the steam vents examined (Table 1). This suggests that an initial successful inoculation may have occurred a year or two earlier and that the organism has since spread to other steam vents. This appears more likely than the simultaneous inoculation of several steam vents from a fairly distant source.

At this point it would be mere speculation to suggest the manner in which *Mastigocladus* inoculum was first transported to Surtsey. The manner in which most micro-algae are dispersed is largely speculation, but at least there has been some work (see Maynard, 1968; Proctor *et al.*, 1967) which indicates that both air and birds are important long distance agents. In the case of *Mastigocladus laminosus* and other true thermophiles on Surtsey the inoculum must have originated from mainland Iceland hot springs or steam vents and have been carried more or less directly to the new site. This "rare source" condition makes such a colonization a less frequent possibility than that involving more ubiquitously distributed mesophilic algae, many of which now occur on Surtsey (Schwabe, 1970, 1972).

There are no thermal waters or steam vents on the Westman Islands of which Surtsey is a part. The hot springs closest to Surtsey are approximately 75—90 km distant near the mouth of Ölfusá, near mid-portions of Thjórsá, and in the Torfajökull region. There is a single warm well near the southern slope of Eyjafjallajökull which is only about 50 km from Surtsey (Barth, 1950), but it is unknown whether *Mastigocladus* occurs there.

Mastigocladus laminosus is a very hardy species and can tolerate desiccation and freezing (Castenholz, 1969a, 1969b, 1970). This should allow fairly easy dissemination if a dispersing agent is present. The world-wide distribution of *Mastigocladus* in hot springs of alkaline to neutral pH supports the hypothesis that *Mastigcaldus* is one of the most easily dispersed thermophiles. Thermo-biologists and other scientists working in thermal areas can become the principal agents for dispersal of thermophilic micro-organisms if precautions are not taken, such as thorough cleaning of boots and collecting equipment. The original introduction of *Mastigocladus* to Surtsey by this means cannot be excluded.

ACKNOWLEDGEMENTS

The author is grateful to the Boston College — NASA Surtsey — Iceland Expedition and the Surtsey Research Society for making possible the collections on Surtsey. The U.S. National Science Foundation has supported the work done in my laboratory.

References:

1. Barth, T. F. W. 1950. Volcanic geology, hot springs, and geysers of Iceland. Carnegie Inst. Wash. Publ. 587, 174 pages.
2. Behre, K. and G. H. Schwabe. 1969. Algenbefunde in den Kraterräumen auf Surtsey Island, Sommer 1968. Vorläufige Mitteilung aus dem MPI. für Limnologie, Plön, 7 pages.
3. Castenholz, R. W. 1969a. The thermophlic cyanophytes of Iceland and the upper temperature limit J. Phycology *5:* 360—368.
4. Castenholz, R. W. 1969b. Thermophilic blue-green algae and the thermal environment. Bacteriol. Reviews *33:* 476—504.
5. Castenholz, 1970. Laboratory culture of thermophilic cyanophytes. Schweizerische z. Hydrologie *32:*538—551.
6. Fremy, P. 1936. Remarques sur la morphologie et la biologie de *l' Hapalosiphon laminosus* Hansg. Ann. Protistologie *5:* 175—200.
7. Maynard, N. G. 1968. Significance of air-borne algae. Z. Allg. Mikrobiol. *8:* 225—226.
8. Proctor, V. W., C. R. Malone, and V. L. DeVlaming. 1967. Dispersal of aquatic organisms: viability of disseminules recovered from the intestinal tract of captive Killdeer. Ecology *48:* 672—676.
9. Schwabe, G. H. 1960. Über den thermobionten Kosmopoliten *Mastigocladus laminosus* Cohn. Blau-Algen und Lebensraum V. Schweizerische Z. Hydrologie *22:* 757—792.
10. Schwabe, G. H. 1970. On the algal settlement in craters on Surtsey during summer 1968. Surtsey Research Progress Report V: 68—69.
11. Schwabe, G. H. 1972. Blue-green algae as pioneers on postvolcanic substrate (Surtsey/Iceland). Proc. 1st Internat. Symposium on Taxonomy and Biology of Blue-green Algae (in the press).

Marine Fungi of Iceland: Calcareophilous Forms

By

A. R. CAVALIERE and A. H. MARKHART III

Department of Biology, Gettysburg College
Gettysburg, Pennsylvania

ABSTRACT

Examinations of shell fragments from the coast of Iceland reveal perforations that resemble the remains of fungal organisms. These fungal-like forms are described, illustrated and discussed.

In a recent report (Cavaliere and Alberte, 1970) several aspects of "shell fungi" were treated, among which was an historical resume, the occurrence, morphology and nature of these organisms.

The discovery of possible penetration of calcareous shells by fungi dates back to the last century. Since then, well over a dozen investigators have reported and described the presence of fungal-like organisms in the shells of an assortment of calcareous organisms.

METHODS AND RESULTS

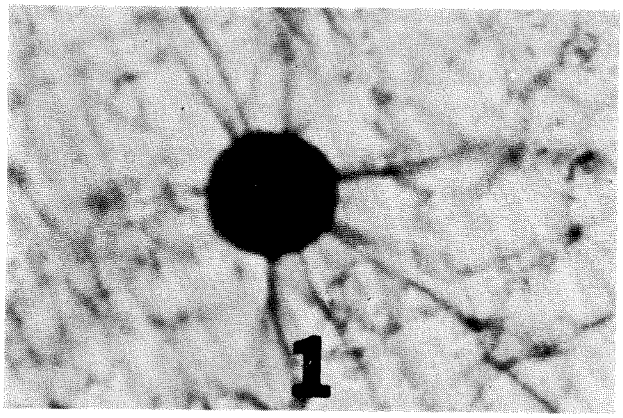
As a result of the total biological investigations of fungi in Iceland and Surtsey, several samples of shell fragments were collected along the mainland coast (Reykjavík, Hafnarfjördur, Keflavík, Grindavík, and Akureyri) as well as along the shores of Surtsey. All the collections made were sifted through graded mesh to separate the minute shell fragments from the predominantly lava and pumice fraction. The most common shell fragments capable of being identified belong to the Mytilidae. The fragments were prepared for observation by mounting them in clear cellulose acetate. This process rendered the specimens stationary without reducing their translucent properties.

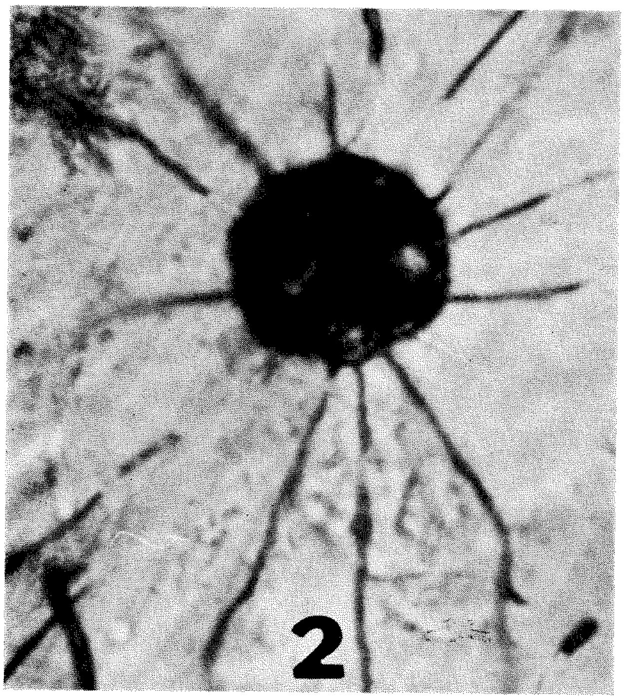
Examinations of shell fragments revealed the common occurrence of four fungal-like forms. Each of the forms are apparently capable of penetrating all three layers of the shell, the periostracum, prismatic and nacreous layers. A very common boring (Figs. 1,2), similar to ones described earlier by Cavaliere and Alberte (1970), is composed of a single, globose sporangium(35μ in diameter) surrounded by 8—15 radiating, sparsely branched hyphae. The hyphae appear to extend some 30—65μ from the sporangium and are about 2μ in width. In several specimens (Fig. 1) a single, central pore, approximately 9μ in diameter, was observed.

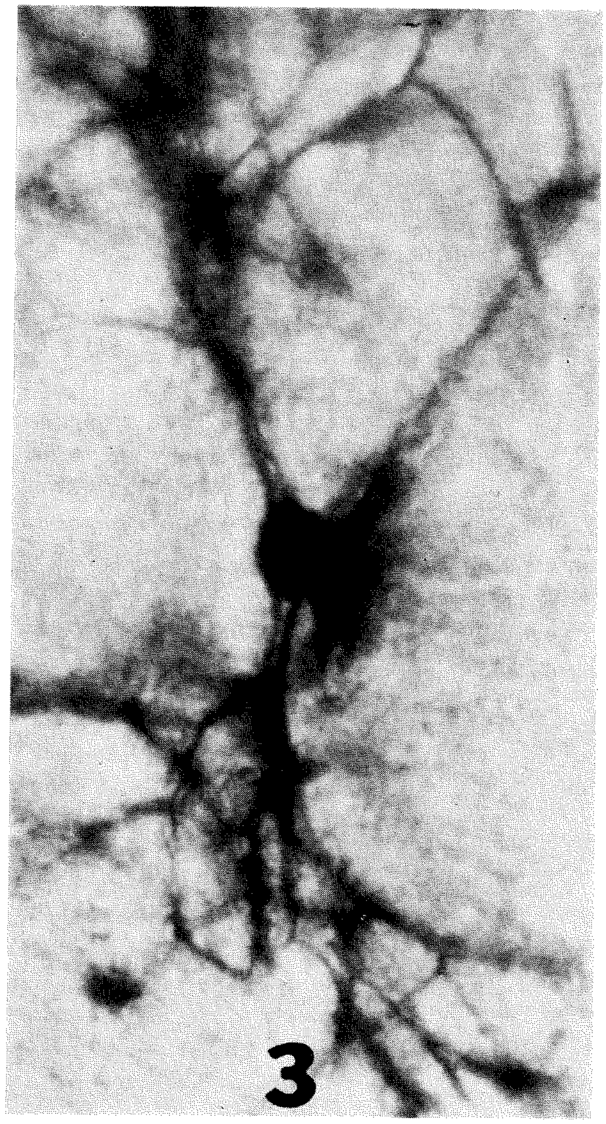
Two additional forms display a much more complex hyphal system. In one (Fig. 3) the single, oval or subspherical fruiting structure measures about 10—16μ in diameter. Two or three stout (3—6μ wide), vegetative hyphae radiate from the sporangium and become profusely branched. The extensive hyphal system may extend over 100μ extramatrically. Another form (Fig. 4) exhibits stout, dichotomously branched hyphae (5—6μ in diameter). Structures which appear to be small sporangia are borne laterally along the hyphal strands.

A final form (Fig. 5) appears quite common in Icelandic shells and has been described several times before (Porter and Zebrowski, 1937; Johnson and Anderson, 1962; Cavaliere and Alberte, 1970). The organism is composed of a massive hyphal and sporangial system. The sporangia are approximately 15μ in diameter, each with a pore opening at the shell surface. The hyphae form a reticulated network which completely ramifies the substrate.

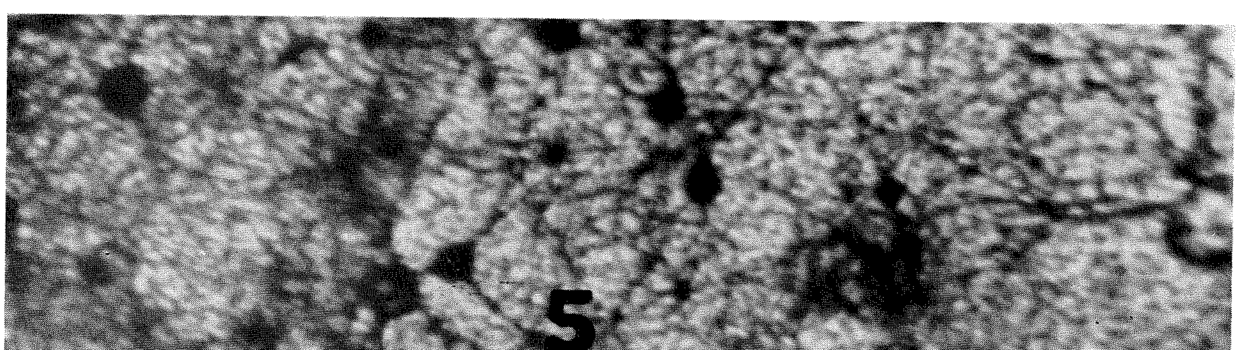
Figures 1—5. Calcareophilous forms. 1,2. Spherical sporangia-like forms with radiating hyphae. 3,4. Fungal-like forms having profusely branched hyphae. 5. Massive sporangial and hyphal system. Figure5, 100X; all others, 200X.


1


2


3


4


5

DISCUSSION

The symmetry of form which tends to reoccur on several types of shells supports the possibility that what is being observed is more than mere tunnelings, cracks or artifacts of the shell. In addition, there are remarkable similarities between these "fungi" which appear in shells and other well known phycomycetous forms. Several factors, however, cast doubts on the actual existence of these fungi. All attempts made to culture them from fresh as well as dried bivalves have thus far failed. Porter and Zebrowski (1937) reported that they were able to isolate spores and hyphae by dissolving the shell fragments, however, our attempts along the same lines have failed. Finally, under the present methods of investigation we have not been able to determine whether we are dealing with fossilized remains of organisms, or indeed if they are fungi, whether they are recent and contemporary forms.

ACKNOWLEDGEMENTS

Support by the United States Atomic Energy Commission, contract AT-(40-1)-3556, and the National Science Foundation, Grant GB-6447 for studies of Icelandic fungi is acknowledged. The senior author is indebted to the personnel of the Museum of Natural History of Iceland for their help and cooperation, and to his students who have spent numerous hours examining slides.

Literature cited:

Cavaliere, A. R. and Randall S. Alberte, 1970: Fungi in animal shell fragments. Jour. Elisha Mitchell Sci. Soc. 86:203—206.

Johnson, T. W., Jr. and W. R. Anderson, 1962: A fungus in *Anomia simplex* shell. Jour. Elisha Mitchell Sci. Soc. 78: 43—47.

Porter, C. L. and G. Zebrowski, 1937: Lime-loving molds from Australian sands. Mycologia 29:252—257.

Diaspores which Drifted to Surtsey 1969

By

STURLA FRIDRIKSSON

The Agricultural Research Institute, Reykjavík, Iceland

As previously stated (Fridriksson 1969), most of the higher plants colonizing Surtsey have grown from seed. As an exception, a few plants have been found growing from stolons and have started to develop following their ocean dispersal. Thus, the *Elymus arenarius* plant, no. 37 in quadrat K17, has obviously developed from a stolon that has drifted to the island and been caught under a protrusion of lava.

This *Elymus* plant developed two leaves, 5 and 3 cm long, during the summer 1969.

In Table 1 are listed plant parts that had been found drifted ashore in 1969. The plant list covers mainly the observations through spring and autumn. These diaspores were mostly found after heavy storms, but no living plant parts were observed in the debris when the shore was searched during the summer months June, July, and August.

All the species listed are, also, found growing on Heimaey and all but one, i.e., *Empetrum nigrum,* are found on the outer islands of the Westman Islands group. The plant parts could thus have drifted from any of the outer islands.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Division of Biology and Medicine, under contract No. AT (30–1) – 3549.

TABLE 1

List of plant parts recorded drifted ashore on Surtsey 1969

	Dates												
	13/4	14/4	22/4	23/4	25/4	27/4	28/4	2/5	3/5	4/5	6/5	13/5	12/9
Angelica archangelica							Se			S			Se
Armeria maritima	LSI					LSR		RL	RSLI	S	ILS		
Cakile maritima			F				F			F			
Cochlearia officinalis		L			LSR	L						L	L
Elymus arenarius			Se	Se		Se	Se						
Empetrum nigrum										SL			SL
Festuca rubra								LS					
Minuartia peploides							Se						Se
Sedum roseum								R		R			L
Silene maritima													F

L = Leaves S = Stem R = Roots I = Inflorescence F = Fruit Se = Seed

Mermaids Purses as Dispersers of Seed

By

STURLA FRIDRIKSSON

The Agricultural Research Institute, Reykjavík, Iceland

During the summer 1969 the shores of Surtsey were regularly searched and records made of the drifting diaspores. The results obtained indicated that rather few seeds were carried by sea currents during the summer months. It was however, noted that during May a number of "mermaids' purses", the capsulated egg of the skate *Raja batis,* drifted ashore. When these were inspected a number of seed were observed attached to the rought outer surface of the "purses". The chitinous material of the purses was somewhat shedded into thin bristles which the seeds stuck to. Some of the seed were hairy which even increased the adhesion effect. The seed discovered on the purses were identified and counted. They are listed in table 1 according to species and quantity of seed per purse.

Except for one infertile fruit of *Carex* the seed found attached to the mermaid purses were all of grass species, which are common in Iceland. These were *Agropyron repens, Elymus arenarius, Phleum commutatum,* and *Alopecurus geniculatus,* However, only *Elymus arenarius* is found growing on the smaller islands of the Westman archipelago (Fridriksson and Johnsen, 1967). But all are found growing on the largest island, Heimaey (Johnsen, 1939) as well as on the mainland of Iceland. All but *Phleum commutatum* are, for example, found on the southern coast near the village Stokkseyri (Fridriksson et al. 1970).

It must be presumed that the seeds and purses got in contact on some neighbouring coast, where the seed got attached, and where from they were dispersed to Surtsey by the "mermaid purses".

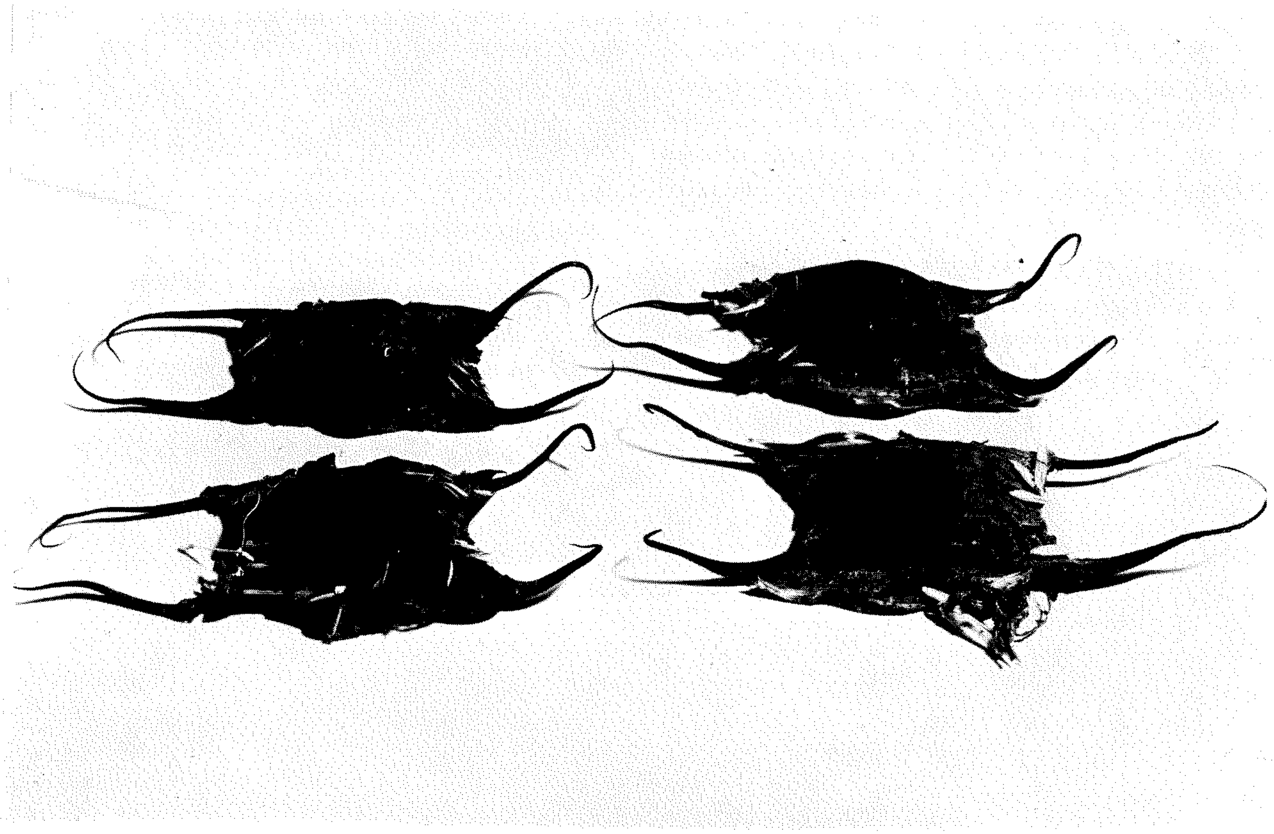
The shortest possible distance of dispersal for this collection of seed, which were attached to the purses, is that from Heimaey to Surtsey, a distance of 20 km.

TABLE 1

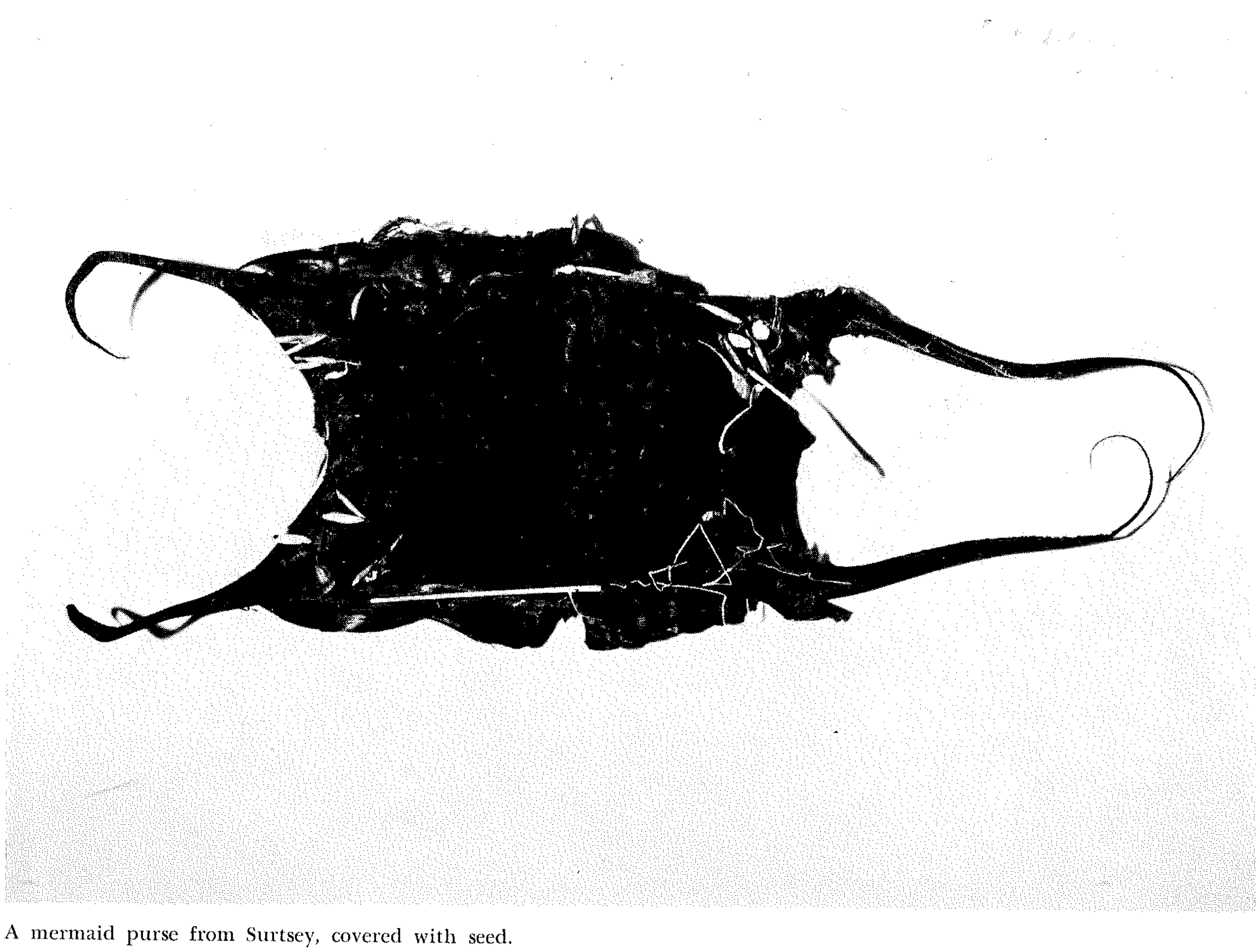
Seeds from mermaid purses of the skate Raja batis

Sample no. of Purses	Species of Seed	Quantity of Seed per Purse	Notations
1	*Agropyron repens* (L) Beauv.*	6	
2	— — Malte	8	
3	— —	2	
4	— —	6	
5	— —	1	
6	— —	3	
6	*Elymus arenarius* L	1	
7	*Agropyron repens*	1	empty spikelet
—	*Phelum alpinum* (syn. *commutatum*)	1	
8	*Elymus arenarius*	1	
9	*Agropyron repens*	1	
10	*Elymus arenarius*	1	immature caryopsis
11	*Agropyron repens*	1	
12	— —	3	
13	*Elymus arenarius*	2	
14	*Agropyron repens*	35	
—	*Elymus arenarius*	3	
15	*Agropyron repens*	1	
16	— —	2	
17	— —	1	
—	*Alopecurus geniculatus* L.	1	
18	*Agropyron repens*	4	
19	— —	4	
—	*Elymus arenarius*	2	
20	*Agropyron repens*	4	
21	— —	18	
—	*Carex* sp.	1	infertile seed
22	*Agropyron repens*	14	
—	*Elymus arenarius*	4	
—	*Alopecurus geniculatus*	1	
23	*Agropyron repens*	3	
—	*Elymus arenarius*	7	
—	*Alopecurus geniculatus*	1	
	Total number of seeds	131	
	Average number of seed per purse 5—6		

* Some of the *Agropyron* seed resemble that of *A. trachycaulum* (Link), but they are probably all *A. repens* (L) Beauv.



Mermaid purses from Surtsey covered with seed.



A mermaid purse from Surtsey, covered with seed.

It has long been known that fishes may eat seed and thus take part in their dispersal. Darwin already experimented with feeding seed to fish, and some seed are used as bait to lure fish with. On the other hand, it is not previously known that fish eggs can also act as dispersers of seed.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Division of Biology and Medicine, under contract No. AT (30–1) – 3549.

References:

Fridriksson, Sturla and Johnsen, Bjrn, 1967: The Vascular Flora of the Outer Westman Islands. Greinar, IV, 3:1–67, Societas Scientiarum Islandica, Reykjavík.

Fridriksson, Sturla; Richter, S. H. and Bjarnason, Á. H., 1970: Preliminary Studies of the Vegetation of the Southern Coast of Iceland, Surtsey Research Progress Report V:20–29.

Johnsen, Baldur, 1939: Observations on the Vegetation of the Westman Islands. Societas Scientiarum Islandica, Vol. XXII.

Elymus Sand Dunes in Iceland

By

STURLA FRIDRIKSSON*, ÁGÚST H. BJARNASON and BJARTMAR SVEINBJÖRNSSON

* The Agricultural Research Institute, Reykjavík, Iceland

On the south coast af Iceland *Elymus arenarius* forms sand dunes over large areas. It has been noted that the topography of these dunes is constantly changing. As *Elymus arenarius* is one of the few plants that grows on Surtsey it is interesting to know how it starts forming the dunes, how large the dunes can get and in what way a dune wanders.

In order to start some preliminary measurements trips were made to Eyrarbakki and Thykkvibaer, which are villages near the south coast where a typical dune landscape exists with dunes of various sizes and shapes. At both places a medium sized dune was selected and measured. The two accompanying drawings show the measurements from Eyrarbakki and Thykkvibaer.

T% is the frequency and M average cover number according to the Hult–Sernander–Du Rietz method of vegetation measurements.

In addition to this study a trip was made to Óseyrartangi the sandspit west of the outlet of Ölfusá, there a precise topography of a 50x50 m quadrat was measured and its vegetation mapped (Fridriksson et al. 1970).

We hope that further investigation and measurements will help in understanding the processes at work in a psammosere which can be compared with that of the blowing sand on Surtsey.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by The Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Division of Biology and Medicine, under contract No. AT (30–1)–3549.

References:

Fridriksson, S., Richter, S. H., Bjarnason, Á. H. 1970: Preliminary Studies of the Vegetation of the Southern Coast of Iceland. Surtsey Reserach Progress Report V.

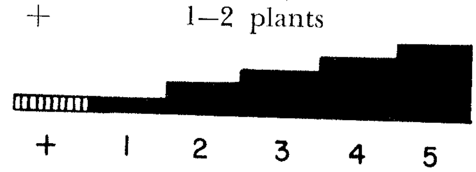
Hylander, N. 1955: Förteckning över Nordens växter: Lund.

Frequency diagrams from dunes in Thykkvibaer and Eyrarbakki, Southern Iceland.

Legend:

according to Hult-Sernander-Du Rietz:

Cover class (M)	Coverage	Average coverage
5	1/2	24/32
4	1/2–1/4	12/32
3	1/4–1/8	6/32
2	1/8–1/16	3/32
1	1/16	1/32
+	1–2 plants	



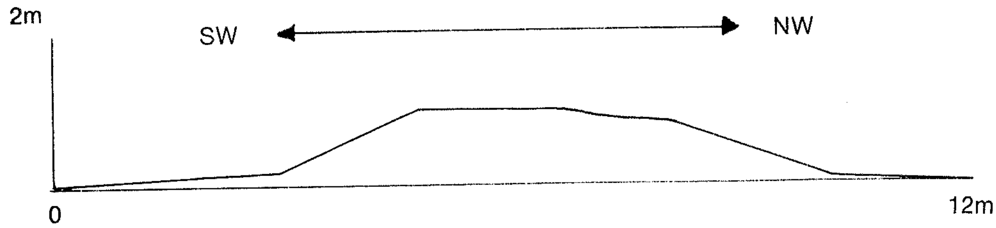
Nomenclature according to: Nils Hylander: Förteckning över Nordens växter; Lund 1955.

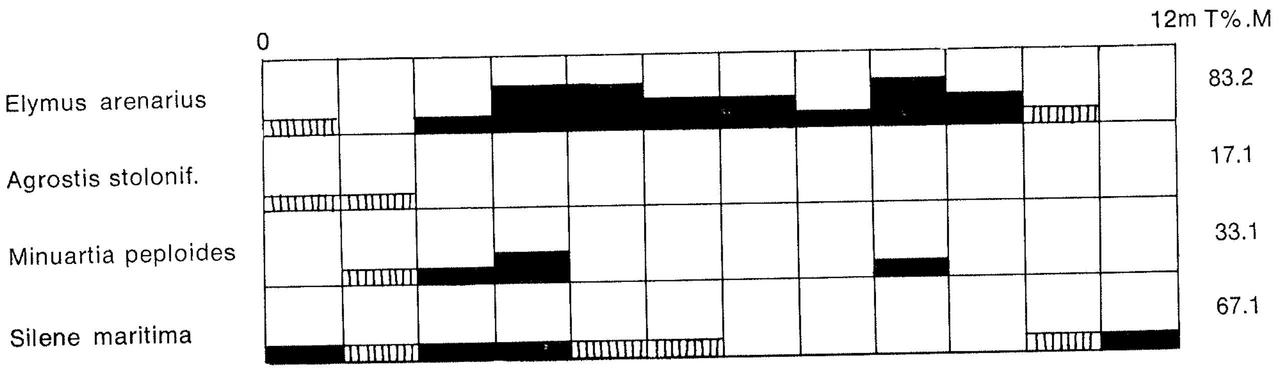
Elymus arenarius L.
Agrostis stolonifera L.
Minuartia peploides (L) Hiern
Silene maritima With.
Cakile maritima Scop. ssp. islandica Hyl.

Following each column is the calculated frequency number in percentage occurrence (T%) and the cover number (M) which is the class of coverage obtained by dividing the sum of coverage number by the number of observations.

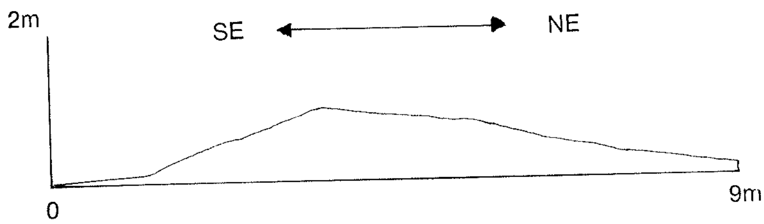
EYRARBAKKI

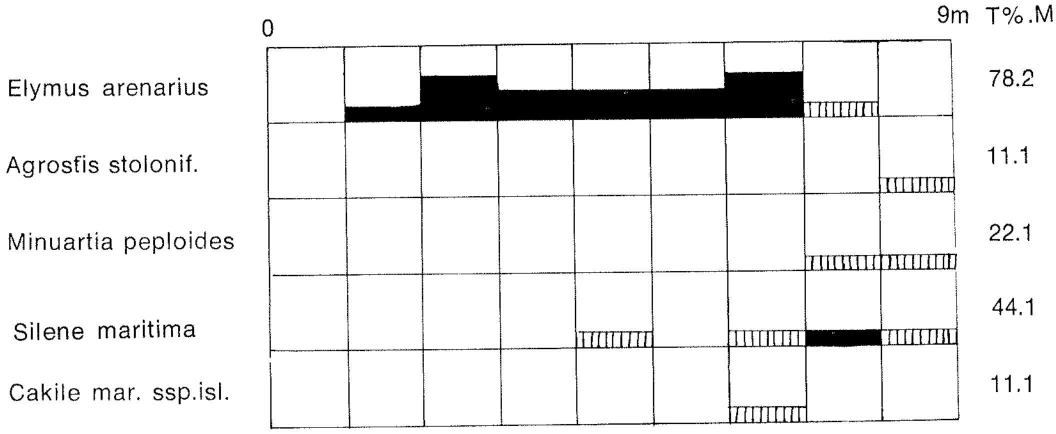
Longitudinal section:





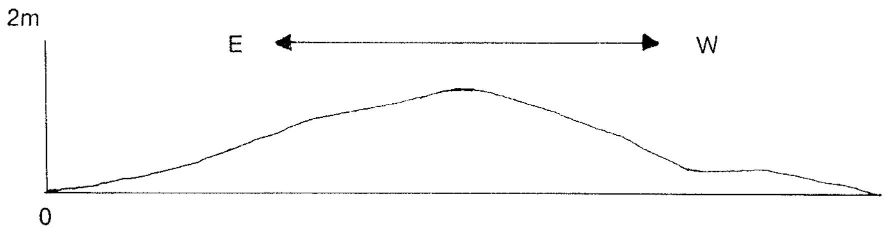
Transverse section:

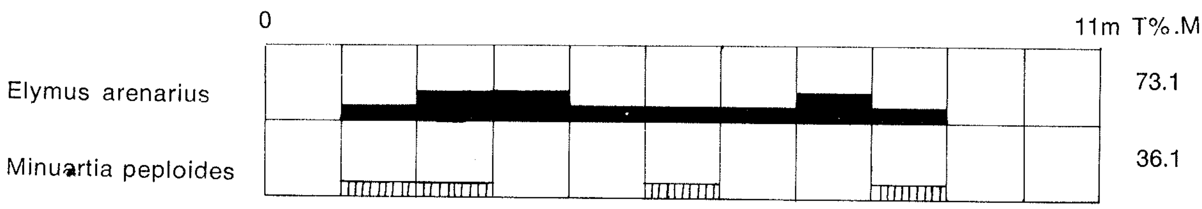




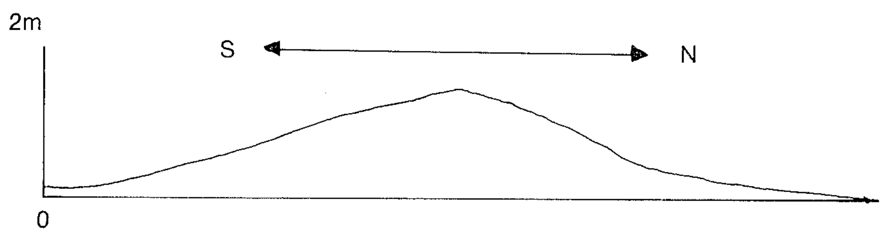
THYKKVIBAER

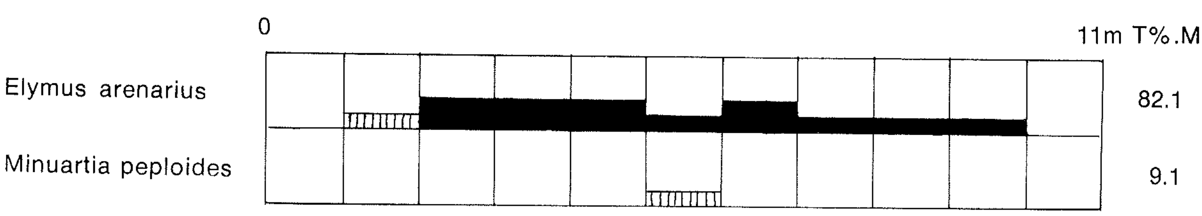
Longitudinal section:





Transverse section:





Vascular Plants in Surtsey 1969

By

STURLA FRIDRIKSSON,* ÁGÚST H. BJARNASON and BJARTMAR SVEINBJÖRNSSON

* Agricultural Research Institute, Reykjavík, Iceland.

During the summer 1969, sixty three vascular plants were found in Surtsey. They were of four species:

Minuartia peploides syn. *Honckenya peploides*	52 plants
Elymus arenarius	5 plants
Cochlearia officinalis	4 plants
Cakile maritima syn. *Cakile edentula*	2 plants

As described in previous reports (Fridriksson and Johnsen 1968, Fridiriksson 1970) the plants were marked with a stake bearing a number, and their positions plotted on an aerial photograph. A detailed topographic map had been prepared of Surtsey in 1969, (Norrman 1970). To that was added the coordinant system previosuly used, with checkers 100 m^2, identified numerically and alphabetically. On the map all the vascular plants found in 1969 were plotted as well as the area of mosses (Fig. 1).

As the individual plants were discovered records were made of their stage of growth and their progress of development followed during the summer. All plants, their location and remarks on over-wintering and development are listed in table I.

Of the colonizing species *Minuartia peploides* is obviously the most aggressive and persistent invader. Of the 52 plants recorded 23 are known to have survived from the previous year. A few other individual plants are, also, suspected to be earlier colonists. This is, however, not definite as their marking stakes had disappeared during the previous winter.

As indicated on the map the plants are primarily colonizing the northern shore and the "old" lava of the eastern side of the island.

On the quadrats B-13 and B-14 a group of *Minuartia* plants were growing among drifted seaweed. This location is at the edge of the lagoon, which has been filled up by sand during the last winters. The high fertility of the soil may to some extent stimulate the growth in this drifting zone.

On the eastern part of the island the old lava (Lava I) is gradually becoming covered with drifting sand. At that location most of the *Minuartia* plants were in their second year. Two of the plants were growing on the southeastern coast on a sand bank and the edge of the lava cliff. As the extensive breakdown of the cliffs will probably continue these plants will consequently be lost.

Of the two *Cakile maritima* plants recorded one was growing with the *Minuartia* plants among the drifted seaweed and the other in quadrat C-12 in a loose and dry sand. The latter plant developed 49 flower buds whereas the former was the only plant on Surtsey forming mature flowers during the summer 1969.

Of the five *Elymus arenarius* plants recorded, two could possibly have overwintered from 1968. One plant in quadrat K-17 had developed from a stolon caught under a nob of lava presumably after having survived the dispersal by ocean.

Of *Cochlearia officinalis* four plants were growing around a plastic barrel filled with rainwater. These plants had obviosuly been carried as seed by birds which were attracted by the water of the barrel, this being the only source of fresh water on the island. It was noted that the plants were growing out of bird droppings in association with some green algae, which gave color to the surfcae of the soil.

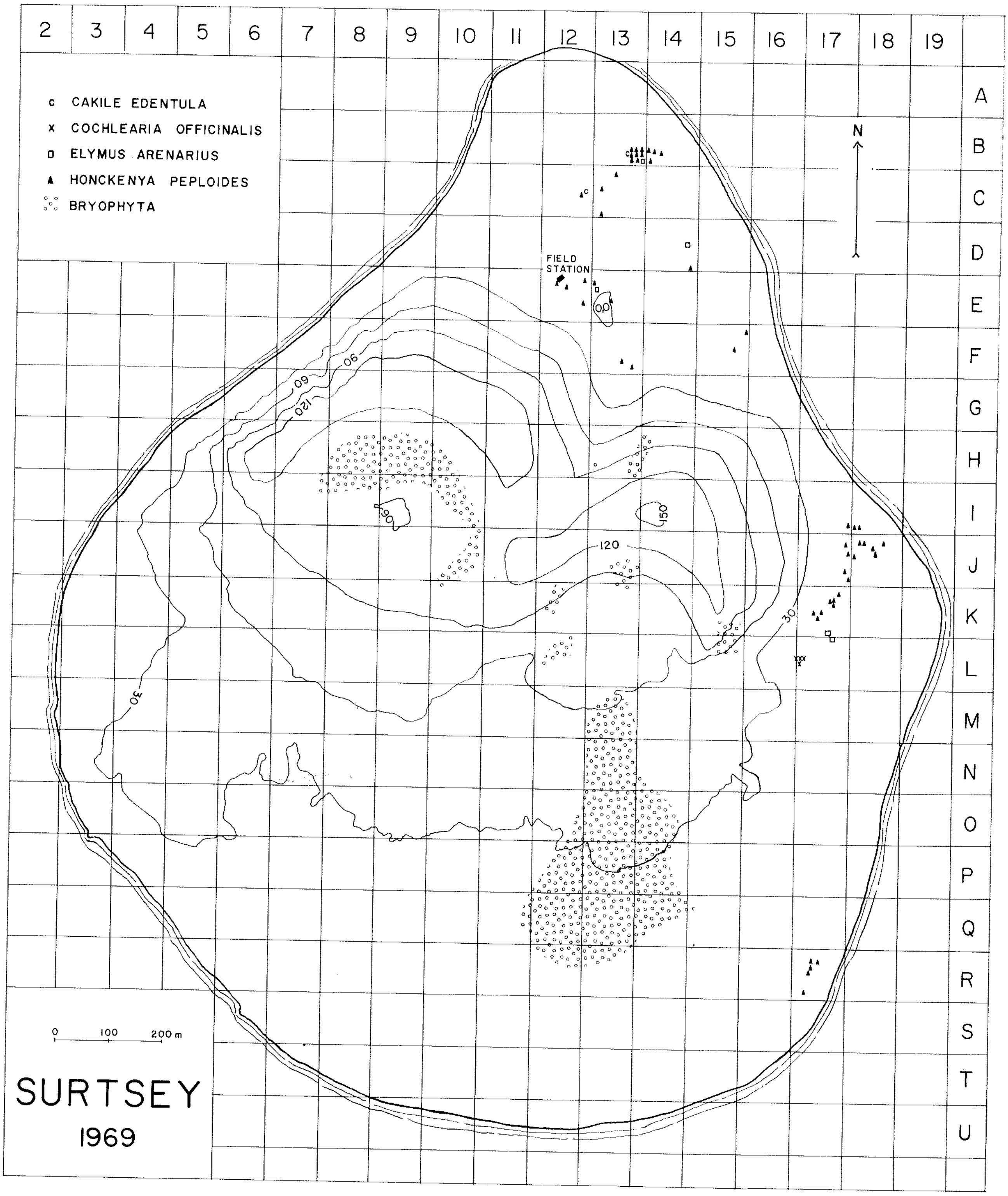


Fig. 1. A map of Surtsey showing the location of plants found on the island in 1969.

TABLE 1
Vascular Plants on Surtsey in 1969

NO:		Location	Plants from 1968	Max. height in cm	Number of branches	Number of leaves	Number of flowerbuds
1	*Minuartia peploides*	E12	×	5.5	9	119	..
2	*Caklie maritima* ssp *isl.*	C12	..	3	2	10	49
3	*Minuartia peploides*	C13	..	½	1	10	..
4	*Elymus arenarius*	B13	..	17	..	3	..
5	*Cakile maritima* ssp *isl.*	B13	..	..	1	7	9
6	*Minuartia peploieds*	B13	..	4	1	11	..
7	*Minuartia peploides*	B13	..	1	1	7	..
8	*Minuartia peploides*	B13	..	½	1	2	..
9	*Minuartia peploides*	B13	..	½	1	2	..
10	*Minuartia peploides*	B13	..	3	1	12	..
11	*Minuartia peploides*	B13	..	½	1	10	..
12	*Minuartia peploides*	B13	..	3	4	26	..
13	*Minuartia peploides*	B14	..	½	1	2	..
14	*Minuartia peploides*	B14	..	1	1	10	..
15	*Minuartia peploides*	B14	..	½	1	8	..
16	*Minuartia peploides*	B13	..	1	1	10	..
17	*Minuartia peploides*	B14	..	3	1	18	..
18	*Minuartia peploides*	C13	..	1.5	1	12	..
19	*Minuartia peploides*	D14	..	5	5	16	..
20	*Minuartia peploides*	E13	×	3.5	1	14	..
21	*Minuartia peploides*	C13	..	½	1	8	..
22	*Minuartia peploides*	J18	×	5	1	31	..
23	*Minuartia peploides*	J18	×	5	1	30	..
24	*Minuartia peploides*	J18	×	1.5	1	14	..
25	*Minuartia peploides*	J18	×	1.5	2	38	..
26	*Minuartia peploides*	I18	×	7.5	3	78	..
27	*Minuartia peploides*	J17	×	½	1	10	..
28	*Minuartia peploides*	F15	×	1	2	22	..
29	*Minuartia peploides*	J17	×	1.5	2	18	..
30	*Minuartia peploides*	J18	×	4	1	30	..
31	*Minuartia peploides*	J18	×	3	1	24	..
32	*Minuartia peploides*	J17	×	2	1	20	..
33	*Minuartia peploides*	K17	×	4	2	40	..
34	*Minuartia peploides*	K17	×	3.5	3	22	..
35	*Minuartia peploides*	K17	×	2	2	30	..
36	*Minuartia peploides*	K18	×	5	4	32	..
37	*Elymus arenarius*	K17	?	15	..	3	..
38	*Minuartia peploides*	R17	×	4	5	46	..
39	*Minuartia peploides*	R17	×	1.5	1	14	..
40	*Minuartia peploides*	R17	×	1	1	10	..
41	*Minuartia peploides*	R17	×	2	2	34	..
42	*Minuartia peploides*	E12	..	½	1	8	..
43	*Minuartia peploides*	C12	..	1.5	1	10	..
44	*Minuartia peploides*	E13	..	1.5	1	14	..
45	*Minuartia peploides*	E12	..	1.5	1	8	..
46	*Elymus arenarius*	E13	..	20	..	3	..
47	*Cochlearia officinalis*	L16	..	..	..	..	..
48	*Minuartia peploides*	F13	×	7	7	140	..
49	*Cochlearia officinalis*	L16	..	..	..	..	..
50	*Minuartia peploides*	J18	..	3	1	20	..
51	*Minuartia peploides*	K17	..	1	2	34	..
52	*Elymus arenarius*	K17	..	5	..	2	..
53	*Minuartia peploides*	I17	..	½	1	8	..
54	*Minuartia peploides*	I18	..	1	1	4	..
55	*Minuartia peploides*	K17	..	½	1	10	..
56	*Minuartia peploides*	K17	..	1	..	8	..
57	*Minuartia peploides*	E12	..	1.5	1	8	..
58	*Minuartia peploides*	R18	..	4	3	42	..
59	*Cochlearia officinalis*	L16	..	..	..	..	..
60	*Cochlearia officinalis*	L16	..	..	..	..	..
61	*Minuartia peploides*	F13	..	..	..	..	..
62	*Minuartia peploides*	F13	..	..	..	..	..
63	*Elymus arenarius*	D14	..	..	..	..	..

All the species recorded have previously been found growing on Surtsey except *Cochlearia officinalis*. These are all common to the coast of Iceland and have been carried to Surtsey by ocean dispersal except the *Cochlearia* plants which most likely were brought by birds.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Division of Biology and Medicine, under contract No. AT (30–1) – 3549.

References:

Fridriksson, S. and Johnsen, B., 1968: The Colonization of Vascular Plants on Surtsey in 1967. Surtsey Research Progress Report IV, pp. 31–38.

Fridriksson, S. 1970: The Colonization of Vascular Plants on Surtsey in 1968. Surtsey Research Progress Report V, pp. 10–14.

Norrman, J. O. 1970: Trends in Postvolcanic development of Surtsey Island. Progress Report on Geomorphological Activities in 1968. Surtsey Research Progress Report V, pp. 95–112.

On the Vegetation of Heimaey, Iceland
Preliminary Report

By
STURLA FRIDRIKSSON*, ÁGÚST H. BJARNASON
and BJARTMAR SVEINBJÖRNSSON
* The Agricultural Research Institute, Reykjavík, Iceland

INTRODUCTION

During the summer of 1969 ecological work on the vascular vegetation of Heimaey was started. Trips were made to the island and preliminary ecological studies carried out. In general the vegetation is dominated by grasses and has clearly been influenced by man especially around the town and main roads.

A study on the vegetation of Heimaey was carried out by Baldur Johnsen (1939), who also made some studies on Bjarnarey. Only few observations have been made since. An extensive study was carried out by Fridriksson and Johnsen (1967) on the vascular flora of the outer Westman Islands. A better knowledge of the vegetation of Heimey was considered necessary as a background for evaluating the colonization of plants on Surtsey.

METHOD OF RESEARCH

The observation was mostly sociological and the method used was that of Hult-Sernander-Du Rietz. A quadrat of 1 m^2 was laid out 5 to 10 times at each locality and the coverage of each plant species indicated by a cover class of 1 to 5 where 5 is the maximum coverage. An average of measurements from the quadrats is then given in the tables with an addition of a frequency number which is the percentage of the quadrats in which the plant species occurs.

By this method two figures are obtained, the average cover class of the quadrats and the frequency; they where then used to classify the communities and societies. Usually the dominating species were used in the classification but notice was also taken of characteristic species.

TOPOGRAPHY AND CLIMATE

The island is of volcanic origin like Surtsey. It is mostly fringed with cliffs but sand beach is found on the isthmus between Stórhöfdi in the extreme south and the main island, and on the isthmus between Heimaklettur in the north and the main island.

The climate is typically oceanic warm and moist in comparison to the mainland.

THE PLANT COMMUNITIES

The vegetation can be divided into seven or eight communities: the dry meadowland, the herb slope, the heath, the gravelly flat, the bog, the sand beach, the cliffs and perhaps the puffin colony which seems to be a derivative of the dry meadowland.

The dry meadowland is the most widespread and is divisible into several societies depending upon the dominating grass species. The most frequent are: *Agrostis tenuis, Anthoxanthum odoratum, Festuca rubra, Festuca vivipara, Poa pratensis* and *Poa trivialis.*

The heath vegetation is characterized by high coverage of *Salix herbacea* and/or *Empetrum hermafroditum.* There are no sharp boundaries but gradual change into dry meadowland.

The main characteristic of the gravelly flat is the open vegetation with the dominating species rarely occurring outside this community such as: *Armeria maritima, Cardaminopsis petrea, Plantago maritima, Silene acaulis* and *Silene maritima.*

The gravelly flat has much in common with the cliffs both in physical factors and plant species but characteristic of the latter are: *Draba* *incana, Oxyria digyna, Polypodium vulgare, Sedum rosea* and *Saxifraga caespitosa.*

The sand beach is mostly bare but wisps of *Minuartia peploides, Mertensia maritima* and *Cakile maritima* were found scattered above high tide mark. Sand dunes with *Elymus arenarius* were also found higher up.

The puffin colony vegetation has but few species but they grow vigorously because of the manure supplied by the birds. Grasses dominate but most characteristic are: *Stellaria media* and *Rumex acetosa.*

The bog community is very small and is gradually disappearing *Carex Lyngbyei* has the highest productivity.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with grant from the U.S. Atomic Energy Commission, Environmental Branch, under the contract No. AT (30–1) – 3549.

References:

Fridriksson, Sturla and Johnsen, Björn: 1967. The Vascular Flora of the Outer Westman Islands, Greinar IV, 3. Societas Scientiarum Islandica.

Hylander, Nils: 1955. Företeckning över Nordens växter, 1. Kärlväxter. (List of the plants of N.W. Europe, 1. Vascular plants.)

Johnsen, Baldur: 1939: Observations on the vegetation of the Westman Islands. Societas Scientiarum Islandica, Vol. XXII.

On the Vegetation of Heimaey, Iceland
II

By
STURLA FRIDRIKSSON*, BJARTMAR SVEINBJÖRNSSON
and SKÚLI MAGNÚSSON
* The Agricultural Research Institute, Reykjavík

ABSTRACT

The island Heimaey, which is the largest member in the group named Westman Islands south of Iceland has been formed in a similar way to Surtsey, i.e., by a submarine volcanic eruption. The northernmost part, however, seems to have been built up by an eruption under a glacier that stretched southwards from the mainland. The island is extremely rocky and fringed on most sides by steep cliffs. The declinity is mostly outwards from the island, so that water does not collect to any extent. Whereas the soil is largely dry and sandy, some parts are rich in manure because of the droppings of the numerous birds on the island. The climate is relatively warm and there is a good deal of precipitation, which is distributed evenly throughout the year.

Vegetation on the island is here divided into eight communities: dry meadowland, the herb slope, heath, gravelly flat, puffin colony, sand beach, cliff and bog communities.

The vascular species found on the island number somewhat over one hundred, and the vegetation of the island shows very little variability. The same species occur in dissimilar communities, beach and alpine plants growing side by side. The poverty of species is due both to difficulties of dispersal from the mainland as well as to the fact that the habitats are very specific and the communities already existing on the island have reached stability although the gravel vegetation seems to be an exception and is in continual succession.

INTRODUCTION

This study of the vegetation of Heimaey was begun in the summer of 1969 (Fridriksson et al. 1971). The vegetation had previously been studied by Baldur Johnsen in 1939, but some time has since elapsed, and it was interesting to compare this vegetation now with that on Surtsey. Thus it was decided to try to make a fairly accurate vegetation map of the island. During the first summer preliminary measurements were made on all the plant-communities, but weather that summer was extraordinarily unfavourable, so that less was accomplished than intended. In the summer of 1970 investigation and sketching of the communities was completed from which the map was prepared. The results of the measurements from the first summer have been revised, particularly the classification of the dry meadowland societies.

METHOD OF RESEARCH

In the summer of 1970 most of the island was investigated. Aerial photographs of the area were used in the field and compared on the site while the vegetation was measured. The distribution of every community was then marked on the photos.

The sociological measurements were in both years performed according to Hult-Sernander-Du Rietz. A quadrat of 1 m^2 was laid out 5 to 10 times at each locality. All plants present were listed and the coverage of each one estimated every time. The average cover of each plant was then calculated by adding the coverage estimates of all the quadrats and dividing by number of observations. These estimates fall into six cover classes:

Cover class	Coverage	Average coverage
5	½ or more	24/32
4	½–¼	12/32
3	¼–⅛	6/32
2	⅛–1/16	3/32
1	less than 1/16	1/32
+	1–2 specimen	0

As an example part of measurements from observation place 16 is cited:

Anthoxanthum odoratum	4	3	2	2	3	100–3
Luzula multiflora	2	1	2	1	1	100–1
Pinguicula vulgaris	1				1	40–1

The first five figures following species names are cover class numbers of the five quadrats observed, then comes the frequency as percentage of quadrats in which the species occurs and behind the hyphen is the average number of cover classes.

After the measurements had been carried out, the communities were grouped and identification letters allocated for relevant communities. It should be mentioned that a closer study proved it was very difficult to classify some of the areas into communities, as they were not clearly defined. The boundaries between the communities are therefore in some cases rather arbitrary.

TOPOGRAPHY

As already stated, the island has been formed by volcanic eruptions at the end of the last Ice Age and subsequently. The volcano Helgafell is situated to the southeast of the town. The island is fringed on most sides with steep cliffs, but there is a sand beach on the isthmus between Heimaklettur and Háin and betwenn Stórhöfdi and the main part of the island, known as Klaufin. In some places the cliffs rise high and form shapely and striking mountains, such as Yztiklettur, Midklettur and Heimaklettur. South of Threalaeidi are Háin, Klifid and Dalfjall. South of Helgafell the ground is flat, but south of the airfield is Saefell, which traverses the island southwards. A large part of the island is covered with lava on which there is a good deal of vegetation. Some shelter is found in Herjólfsdalur and there is a grassy dell near Saefell, but otherwise the ground is rather barren.

The landscape has in many places been affected by man and animals. For instance, roads have been laid across the island, and road-building material has been taken from the eastern slopes of Helgafell.

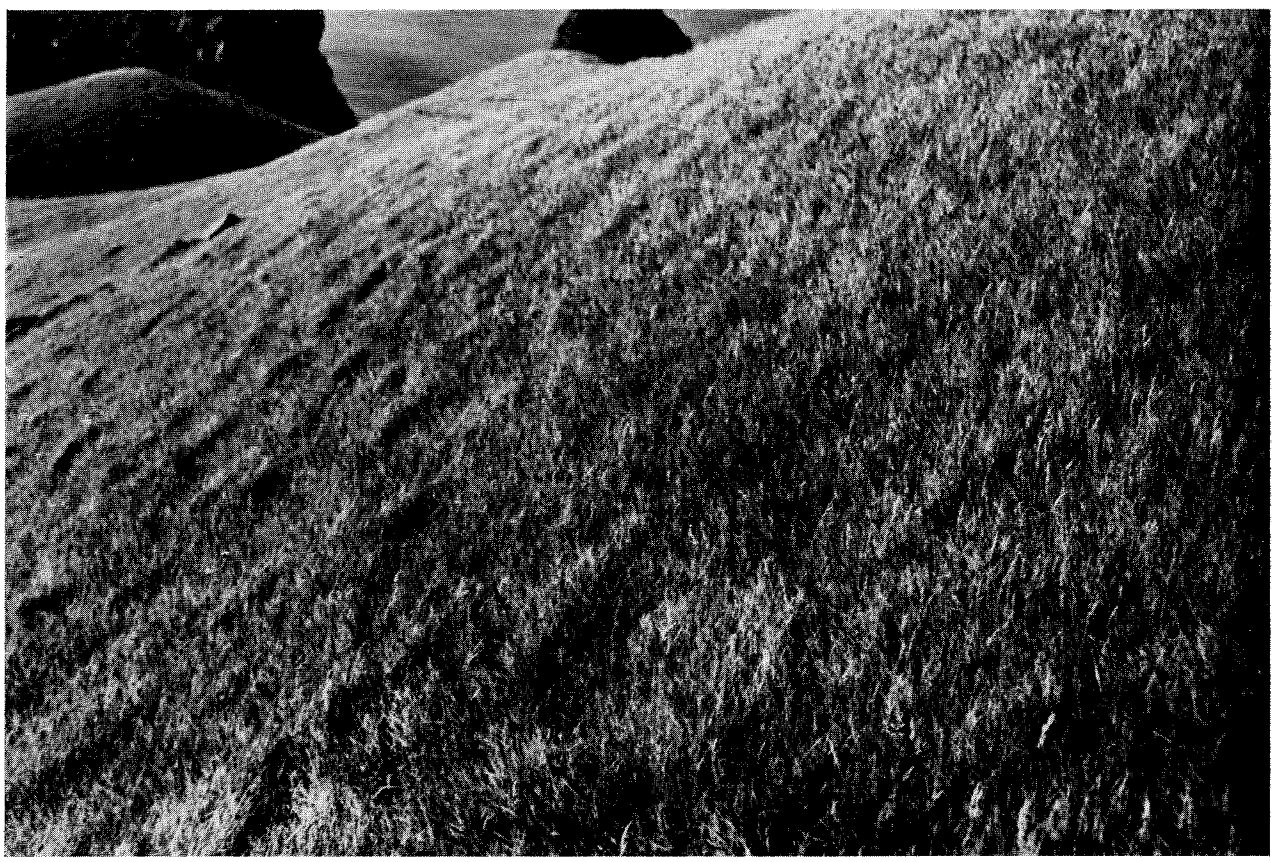
CLIMATE

The effects of weather are very noticeable. Heimaey is situated south of the mainland, where the climate is extremely oceanic, with mild winters and much precipitation. It is very windy, so that sea spray greatly affects the composition of the vegetation. A weather reporting station is located on Stórhöfdi at the southern extremity of the island. The following records are obtained from there, supplied by the courtesy of the Icelandic Meteorological Office:

Only at six other stations in Iceland have annual mean precipitation recordings been higher, the maximum is at Vík in Mýrdal, 2256 mm. The annual mean temperature is the third highest, showing a maximum of 5.7°C. At Heimaey are fewer days of frost in summer than on the mainland, the temperature fluctuations are fairly small, and there are by far the most days with fog for the whole of Iceland.

Month	J	F	M	A	M	J	J	A	S	O	N	D	The Whole Year
Amount of precipitation (mm), mean for 1931–1960	138	104	109	97	81	81	84	108	132	166	141	156	1937
Mean temperature °C 1931–1960	1.4	1.6	2.7	3.7	6.2	8.5	10.3	10.2	8.4	5,6	3.8	2,5	5.4
Mean number of days when frost occurred 1951–1960	14	13	11	6	3	0	0	0	0.6	3	6	13	70
Temperature °C, 1931–1960:													
Mean daily minimum	–0.6	–0.5	0.8	1.7	4.6	7.0	8.8	8.7	7.0	4.1	2,8	0,5	
Mean daily maximum	3.5	3.8	4.6	5.9	8.7	11.1	12.8	12.6	10.5	7.4	5.6	4.6	
Number of days with fog, mean for 1931–1960	2.4	2.4	3.6	4.5	7.0	8.7	10.0	9.2	8.3	5.4	4.7	3.0	69.2


North-eastern slopes of Helgafell. Dry meadowland and gravelly flat communities. (A_1 and C_2.) (Photo by S. Magnússon.)


The dry meadowland. (A_3.) The eastern slopes of Heimaklettur. (Photo by Á. H. Bjarnason.)

VEGETATION

The vegetation is in our study divided into eight communities: the dry meadowland, the herb slope, the puffin ground, the gravelly flat, the heath, the sand beach, the bog and the cliff community. The dry meadowland covers the largest area of land and is dominated by grasses.

The herb slope has the greatest variety of species, which is indicated in the table.

The puffin ground shows very little variety of species but excellent growth. This community is usually found on slopes.

Gravelly flat communities are rather widespread, and until recently there has been considerable erosion in this area, probably because of the encroachment of sheep. There are many species, but typical gravel plants are the most common.

The heath community is mostly found in the dry lava fields.

There is little coastal vegetation as such, for the island is largely fringed with steep cliffs, so that the vegetation merges with cliff vegetation. There is, however, a sand beach with *Minuartia peploides, Mertensia maritima* and *Elymus arenarius* on Thraelaeidi and Klaufin.

There are two boggy patches in Herjólfsdalur, where some species, not found elsewhere on the island, are growing but this community seems to be deteriorating.

There is much cliff vegetation, especially in and near the breeding areas of the fulmar and kittiwake.

On the following pages are tables listing species which were found growing in the various societies. The distribution of the societies and the areal of the various communities can be seen on the accompanying map. The × mark means that the plant was found growing in the society but did not happen to be in any of the quadrats.

THE DRY MEADOWLAND COMMUNITY

The community of the dry meadowland being the most widespread may be subdivided into four societies according to the predominant types and the composition of the species A1—4.

A1 *Agrostis tenuis — Anthoxanthum odoratum* society and A4 *Festuca vivipara — Anthoxanthum odoratum* society are fairly similar, but the former develops better and is on moister soil. A2 *Festuca rubra* society and A3 *Festuca rubra — Poa pratensis* are also very similar on similar soil.

A DRY MEADOWLAND

A1: Agrostis — Anthoxanthum society

	65	58	43	48
Achillea millefolium	40—2	100—1	×	×
Agrostis tenuis	100—4	100—2	100—2	100—3
Alchemilla vestita	..	60—3	40—1	×
Anthoxanthum odoratum	100—2	100—2	100—2	100—2
Angelica archangelica	..	×	..	..
Botrychium lunaria	..	60—1	×	80—1
Cardamine pratensis	..	..	20—1	..
Carex flacca	..	20—1	×	60—1
Cerastium fontanum	..	40—1	..	..
Empetrum hermafroditum	..	..	×	..
Equisetum arvense	..	..	100—1	..
Equisetum pratense	60—2	..	100—2	100—2
Erigeron boreale	..	×	..	..
Euphrasia frigida	..	80—1	..	..
Festuca rubra	80—2	100—1	100—1	100—2
Festuca vivipara	..	..	×	100—1
Galium Normanii	..	..	×	..
Galium verum	..	80—2	100—1	100—2
Gentianella amarella	..	20+	..	..
Gentianella aurea	..	×	..	×
Gentianella campaestris	..	×	..	×
Lathyrus pratensis	100—3	..	..	..
Leontodon autumnalis	..	80—2	20—1	..
Luzula multiflora	80—1	100—1	80—1	100—1
Myosotis arvensis	..	100—1	..	×
Plantago lanceolata	..	60—1	..	..
Poa pratensis	100—1	40—1	100—1	100—1
Plantago maritima	..	×	..	..
Polygonum viviparum	..	..	×	..
Potentilla anserina	..	×	..	..
Prunella vulgaris	..	×	..	..
Puccinellia retroflexa	..	40—1	..	..
Ranunculus acris	..	100—2	×	60—1
Rhinanthus minor	..	40—1	..	..
Rumex acetosa	60—1	40—1	60—1	×
Sagina nodosa	..	×	..	..
Salix herbacea	..	..	×	..
Selaginella selaginoides	..	..	20—1	..
Stellaria media	..	..	×	..
Succisa pratensis	..	20—1	..	..
Taraxacum sp.	..	60—2	20—1	40—1
Trifolium repens	..	×	×	80—2
Thymus Drucei	..	40—1	..	×
Veronica officinalis	..	..	×	×
Viccia cracca	..	×	..	..

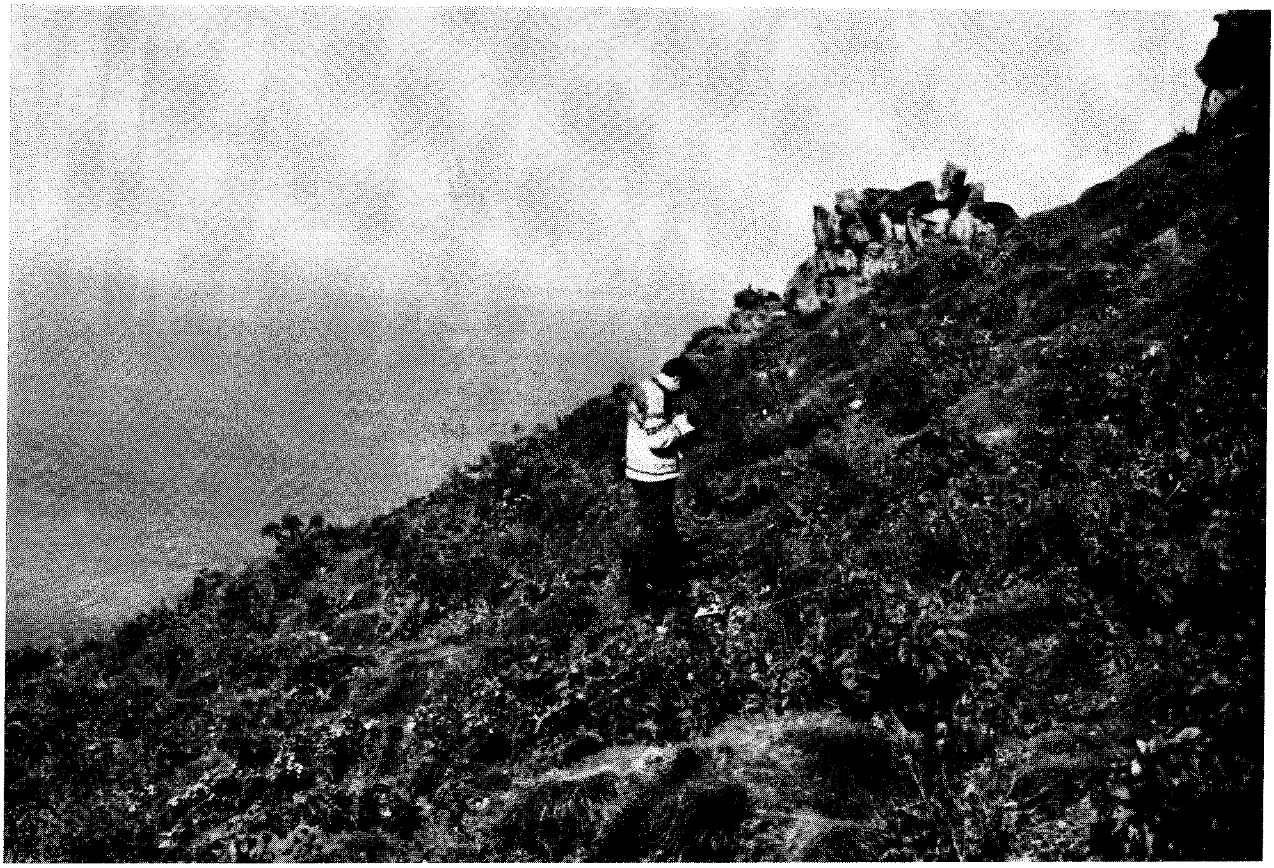
A2: Festuca rubra society	34	30	12	32	44	10	4	2	69	9	8
Achillea millefolium	..	..	..	..	..	..	..	60–1	100–2	..	..
Agrostis stolonifera	..	..	..	100–1	..	..	..	..	×	..	..
Agrostis tenuis	..	..	..	..	20–1	..	40–1	..	..	..	..
Alchemilla vestita	..	..	..	..	..	..	..	..	..	..	..
Anthoxanthum odoratum .	..	100–1	..	..	..	..	..	80–3	..	..	..
Armeria maritima	80–1	..	40–1	×	60–1	..	100–1	×	..	..	40–1
Botrychium lunaria	..	..	..	×	..	..	..	..	..	..	..
Cardaminopsis petrea	..	..	..	..	×	..	..	..	..	..	..
Carex flacca	..	..	..	..	..	..	..	20–1	..	..	..
Cerastium alpinum	..	..	..	..	40–1	..	..	..	..	..	..
Cerastium fontanum	100–1	20–1	40–1	100–1	..	100–2	100–1	20–1	80–1	80–1	..
Coeloglossum viride	..	×	..	..	..	..	..	..	..	..	..
Cystopteris fragilis	..	..	..	..	20–1	..	..	..	..	..	..
Draba incana	..	..	..	..	..	..	..	×	..	..	..
Elymus arenarius	..	..	..	..	..	..	..	..	..	×	..
Empetrum hermafroditum	..	60–1	..	..	×	..	60–1	..	..	..	..
Equisetum arvense	100–2	100–2	..	×	100–1	100–3	..	100–1	..	..	..
Equisetum pratense	..	..	..	..	..	..	..	..	..	..	..
Euphrasia frigida	..	..	..	..	..	..	..	..	40–2	..	..
Festuca rubra	100–3	100–3	100–4	100–5	100–1	100–3	100–2	100–3	100–4	100–5	100–5
Festuca vivipara	..	..	..	×	80–1	..	..	..	..	..	..
Galium Normanii	..	..	..	×	..	60–1	..	..	..	..	..
Galium verum	..	100–1	..	100–1	60–1	100–2	..	80–1	100–2	40–1	..
Gentianella aurea	..	..	..	..	..	..	..	..	×	..	..
Lathyrus maritimus	..	..	..	..	..	..	..	..	..	×	..
Lathyrus pratensis	..	100–3	..	..	..	..	..	..	..	..	..
Leontodon autumnalis ..	..	..	×	×	..	..	..	×	×	..	..
Luzula multiflora	..	80–1	80–1	80–1	×	60–1	..	60+	..		
Luzula spicata	..	..	..	×	80–1	20–1	60–1	×	.		
Myosotis arvensis	..	..	..	..	..	..	..	..	×	.	
Oxyria digyna	..	..	..	..	60–1	..	..	..	..	..	..
Pinguicula vulgaris	..	..	..	×	..	..	..	..	..	..	..
Plantago lanceolata	..	..	..	..	..	..	..	..	60–1	..	..
Plantago major	..	20–1	..	..	..	..	..	..	..	..	..
Plantago maritima	..	..	20–1	..	×	20–1	80–1	60–1	..	20–1	..
Poa pratensis	..	..	40–1	..	..	40–1	..	..	80–1	..	..
Polygonum viviparum ..	..	100–1	..	..	100–1	..	..	100–1	..	..	..
Potentilla anserina	..	..	..	..	..	..	..	..	×	..	..
Ranunculus acris	..	..	..	..	..	..	..	..	60–1	..	..
Rhinanthus minor	..	20–1	..	..	..	..	..	..	..	..	..
Rumex acetosa	20–1	×	..	×	60–1	..	..	60–1	..	..	..
Salix herbacea	..	80–1	..	×	80–2	..	20–1	60–2	..	..	..
Saxifraga caespitosa	..	..	..	..	40–1	..	..	..	..	..	..
Silene acaulis	..	..	..	..	40–1	..	80–1	..	..	..	..
Silene maritima	..	..	..	..	..	..	..	..	80–1	..	..
Stellaria media	..	..	..	×	..	..	..	..	..	..	..
Succisa pratensis	..	..	..	..	..	..	..	..	×	..	..
Taraxacum sp.	..	..	..	..	..	..	..	×	20–1	..	..
Thymus Drucei	..	60–1	100–2	×	100–1	60–1	100–2	40–1	80–2	..	..
Thalictrum alpinum	..	..	..	..	×	..	..	80–1	..	..	..
Trifolium repens	..	20–1	..	..	..	..	..	..	×	..	..

A3: Festuca — Poa pratensis society

	2	6	14	15	21	23	38	39	40	47	60	62	71	70—3
Achillea millefolium	..	..	×	40—1	..	..	20—1	20—1	..	..	..	100—2	100—1	100—2
Agrostis stolonifera	..	..	..	..	..	..	..	..	..	..	..	60—1	..	100—1
Agrostis tenuis	..	..	..	..	..	..	..	..	..	80—1	100—3	..	100—2	..
Alchemilla vestita	..	..	..	..	..	..	60—1	60—1	..	..	..	40—2	..	..
Angelica archangelica	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Anthoxanthum odoratum	..	80—1	100—2	100—2	..	100—2	100—2	100—2	100—4	100—2	..	60—1	60—1	40—2
Armeria maritima	..	..	..	..	×	..	..	..	40—1	..	..	..	..	..
Botrychium lunaria	..	..	..	20—+	20—1	..	20—1	20—1	40—1	100—1	..	..	..	..
Cardamine pratensis	..	..	..	×	..	..	100—2	100—2	..	..	..	..	..	40—1
Carex flacca	..	..	..	..	..	..	60—1	60—1	100—1	..	..	..	..	..
Cerastium alpinum	..	..	..	..	..	..	..	..	100—1	×	..	..	20—1	..
Cerastium fontanum	40—1	100—1	40—1	80—1	100—2	101—1	..	..	..	100—1	..	..	100—1	100—1
Draba incana	..	..	..	..	×	..	..	..	..	..	..	..	..	..
Deschampsia caespitosa	..	..	..	..	..	..	..	..	..	..	..	×	..	..
Erigeron boreale	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Equisetum arvense	100—2	..	..	100—4	100—2	100—2	80—1	80—1	100—2	100—1	..	100—2	..	100—1
Equisetum pratense	..	..	..	..	..	100—3	100—3	..	..	100—2	..	..	..	..
Euphrasia frigida	..	..	..	..	×	..	..	..	..	..	..	×	20—1	20—1
Festuca rubra	100—3	100—2	100—2	..	100—2	100—3	100—1	100—1	100—2	100—2	100—1	100—2	100—3	100—4
Festuca vivipara	40—1	..	..	..	×	..	100—2	100—2	..	80—1	..	20—1	..	×
Filipendula ulmaria	..	..	..	..	..	..	..	..	..	..	..	..	..	40—1
Galium Normanii	80—1	..	60—1	..	40—1	..	..	..	..	..	..	..	..	..
Galium verum	100—1	60—1	80—1	80—1	60—1	100—1	20—1	20—1	80—1	100—1	20—1	×	..	100—1
Kobresia myosuroides	..	..	..	..	×	..	..	..	..	..	..	..	..	..
Leontodon autumnalis	..	×	..	..	20—1	40—1	..	..	..	80—1	20—1	100—3	..	..
Luzula multiflora	80—1	40—1	100—1	80—1	80—1	100—1	100—1	100—1	100—1	100—1	40—1	60—1	×	×
Luzula spicata	..	..	..	..	×	20—1	..	..	..	..	..	×	..	..
Myosotis arvensis	..	..	..	..	×	..	..	..	60—1	..	..	80—1	100—1	60—1
Parnassia palustris	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Pinguicula vulgaris	..	..	×	..	×	..	..	..	..	..	..	..	..	..
Plantago lanceolata	..	..	..	..	×	..	..	..	40—1	..	..	..	×	×
Poa pratensis	100—2	100—3	100—2	100—2	100—3	100—3	100—2	100—2	100—1	100—1	100—2	100—2	100—2	100—1
Polygonum viviparum	..	..	..	..	20—1	80—1	..	..	..	100—1	..	..	..	×
Ranunculus acris	..	100—1	×	20—1	×	80—1	×	×	..	..	..	40—1	×	100—1
Rhinanthus minor	..	..	..	..	20—1	100—1	..	..	..	..	..	..	..	×
Rumex acetosa	..	100—1	20—1	100—1	40—1	100—1	..	..	20—1	60—1	40—1	80—1	..	100—1
Rumex longifolius	..	..	..	..	..	..	..	..	..	..	..	20—1	..	..
Sagina procumbens	..	..	..	..	×	..	..	..	..	..	..	..	..	..
Saxifraga caespitosa	..	..	..	..	×	.	..	..	..	..	..	..	..	..
Saxifraga hypnoides	..	..	..	..	..	..	..	..	..	..	..	..	..	20—1
Silene acaulis	..	..	..	..	×	..	..	..	..	..	..	..	..	..
Stellaria media	..	..	..	..	40—1	..	..	..	×	..	..	..	..	..
Taraxacum sp.	..	..	..	..	20—1	..	..	..	..	..	..	40—1	×	40—1
Thymus Drucei	80—1	..	80—1	..	60—1	..	..	..	80—1	100—2	..	..	..	×
Trifolium repens	..	..	..	..	..	..	..	..	..	..	..	..	×	..

A4: Festuca vivipara — Anthoxanthum odoratum society

	16	22	35	41	50	53	64	55
Achillea millefolium	..	..	..	40—1	..	..	..	..
Agrostis stolonifera	..	..	..	..	100—2	100—1	60—1	..
Agrostis tenuis	..	..	..	100—1	..	..	..	100—1
Alchemilla vestita	..	..	×	80—1	40—1	×	..	40—1
Anthoxanthum odoratum	100—3	100—1	40—1	100—2	100—2	100—1	100—2	100—2
Armeria maritima	20—1	..	×	..	40—1	..	..	×
Botrychium lunaria	..	20—1	80—1	20—1	20—1	20—1	..	..
Calluna vulgaris	..	..	..	..	..	..	..	60—1
Cardamine pratensis	..	..	×	..	..	..	..	..
Cardaminopsis petrea	..	..	..	..	..	..	..	×
Carex flacca	..	40—1	..	20—1	..	80—1	×	80—1
Cerastium alpinum	..	..	×	..	40—1	..	..	..
Cerastium fontanum	80—1	80—1	..	100—1	80—1	..	60—1	60—1
Coeloglossum viride	..	..	..	..	..	..	..	100—1
Empetrum hermafroditum	..	100—2	×	..	20—1	100—1	..	100—1
Equisetum arvense	100—1	100—1	100—2	100—1	60—1	100—1	..	..
Equisetum pratense	..	..	..	80—1	..	40—1	100—2	..
Erigeron boreale	..	..	×	×	..	..	..	20+
Festuca rubra	..	100—3	100—1	100—3	100—1	100—2	..	..
Festuca vivipara	100—1	100—3	100—4	100—1	100—2	100—2	100—2	100—2
Galium Normanii	80—1	80—1	80—1	..	..	..	..	×
Galium verum	..	100—1	100—1	100—2	100—1	100—1	100—1	100—1
Gentianella campestris	..	..	..	..	..	..	..	20—1
Juncus trifidus	..	..	..	..	40—1	..	..	..
Lathyrus pratensis	..	..	×	..	..	×	..	..
Luzula multiflora	100—1	100—1	100—1	100—1	100—1	80—1	100—2	100—1
Luzula spicata	20—1	20—1	..	..	80—1	..	20—1	..
Myosotis arvensis	..	..	..	20—+	..	..	20—1	..
Pinguicula vulgaris	40—1	..	×	..	..	..	..	..
Plantago lanceolata	..	..	×	60—1	..	..	..	..
Plantago maritima	..	..	..	×	80—1	..	..	..
Poa pratensis	..	100—1	..	60—1	60—1	100—1	40—1	..
Polygonum viviparum	100—1	80—1	100—1	60—1	..	20—1	..	100—1
Prunella vulgaris	..	..	×	×	..	..	..	..
Ranunculus acris	..	×	..	..	..	..	..	..
Rhinanthus minor	..	..	..	..	..	..	..	20—1
Rumex acetosa	60—1	×	×	..	40—1	..	..	..
Sagina sp.	..	40—1	..	..	..	..	..	..
Salix herbacea	100—1	100—1	100—1	..	..	60—1	..	40—1
Selaginella selaginoides	..	..	60—1	..	×	..	..	..
Silene acaulis	40—1	..	..	..	..	..	..	..
Succisa pratensis	..	..	..	20—1	..	..	×	×
Taraxacum sp.	..	×	..	100—1	20—1	..	..	×
Thalictrum alpinum	..	..	..	..	×	..	..	..
Thymus Drucei	100—1	80—1	100—1	60—1	100—1	20—1	100—3	100—1
Trifolium repens	..	..	×	..	..	..	60—1	..
Trisetum spicatum	..	..	..	..	..	..	40—1	..
Veronica officinalis	..	..	..	×	..	..	..	×



The puffin colony. The western slope of Heimaklettur. Photo by Á. H. Bjarnason.

A5: Herb slope society	67	57	66
Achillea millefolium	100—2	100—1	100—2
Agrostis stolonifera	80—1	..	100—3
Agrostis tenuis	..	100—1	..
Alchemilla alpina	20—1	×	..
Alchemilla vestita	80—1	20—1	20—2
Angelica archangelica	..	..	..
Anthoxanthum odoratum	100—1	..	100—2
Botrychium lunaria	..	×	..
Carex flacca	..	80—1	..
Carex rariflora	..	..	20—1
Cerastium fontanum	100—1	20—1	..
Cystopteris fragilis	..	×	..
Empetrum hermafroditum	40—1	×	..
Equisetum arvense	×	60—1	..
Equisetum pratense	..	60—1	100—2
Erigeron boreale	20+	×	..
Euphrasia frigida	60—1	..	..
Festuca rubra	100—1	100—1	80—1
Festuca vivipara	40—1	40—1	..
Filipendula ulmaria	×	..	..
Galium verum	100—1	100—1	×
Gentianella amarella	×	..	..
Gentianella campestris	100—1	40—1	..
Hieracium sp.	×	×	..
Kobresia myosuroides	..	20—1	..
Leontodon autumnalis	..	60—1	100—1
Luzula multiflora	100—1	100—1	..
Luzula spicata	20—1	..	..
Myosotis arvensis	..	40—1	..
Plantago lanceolata	×	100—2	20—1
Plantago maritima	100—2	60—1	..
Poa pratensis	80—1	100—1	..
Poa trivialis	×	..	80—2
Polygonum viviparum	100—1	60—1	..
Prunella vulgaris	..	×	..
Ranunculus acris	20—1	20—1	80—1
Rhinanthus minor	100—1	20—1	20—1
Rumex acetosa	×	×	×
Sagina nodosa	..	40—1	..
Salix herbacea	..	20—1	..
Sieglingia decumbens	..	100—1	..
Succisa pratensis	100—2	100—2	..
Taraxacum sp.	×	60—1	100—2
Thymus Drucei	100—2	80—1	..
Trifolium repens	×	×	60—2
Veronica officinalis	..	×	..
Viccia sepium	×	..	..

THE HERB SLOPE*

A characteristic of this society is the great variety of species, and especially the herbs which are more numerous and widespread than in other societies, such as: *Achillea millefolium, Alchemilla vestita, Erigeron boreale, Filipendula ulmaria, Gentianella campestris, Plantago lanceolata, Ranunculus acris, Rhinanthus minor* and *Succisa pratensis.* Some of the most conspicuous are: *Achillea millefolium, Plantago lanceolata, Rhinanthus minor* and *Taraxacum* sp.

This society is found on dry, sandy slopes, often facing south. In such habitats the passage of sheep and people frequently disturbs the vegetation.

THE PUFFIN GROUND COMMUNITY

It is doubtful whether this kind of vegetation should be regarded as a separate community but although perhaps artificial this convenient classification is used. It is noteworthy that where the puffin starts to nest, the slopes retain to some extent their vegetation characteristics, i.e., the main grasses remain the same as before, but the large amount of manure makes the number of species fewer than otherwise, and individual species are more widespread than they are outside such habitats, e.g., *Stellaria media, Rumex acetosa.* The most abundant species of the puffin slopes are: *Festuca rubra, Poa pratensis* and *Poa trivialis.*

THE GRAVELLY FLAT COMMUNITY

The gravelly flats are quite variable and the number of species does not give a true cross section. It is most abundant near the edges of a denser vegetation. Characteristic species are: *Armeria maritima, Cardaminopsis petrea, Cerastium alpinum, Cerastium fontanum, Silene acaulis* and *Silene maritima.* Also common are *Festuca rubra, Festuca vivipara, Luzula spicata, Plantago maritima* and *Thymus Drucei.* Characteristic features is the open soil with the low frequency and cover of plants. Some species have a clustered distribution, i.e., *Armeria maritima, Silene acaulis* and *Silene maritima.* Others have a more regular or random distribution. There is an obvious resemblance between the gravelly flat community and the cliff community, especially where there are bigger bolders among the gravel. The gravelly flats are open areas, which have lost the fertile top layer of soil through erosion. In areas where the erosion is recent the gravel is mixed with the remnants of the topsoil. In this "flag" type of soil *Cerastium fontanum* and *Sedum villosum* are found growing.

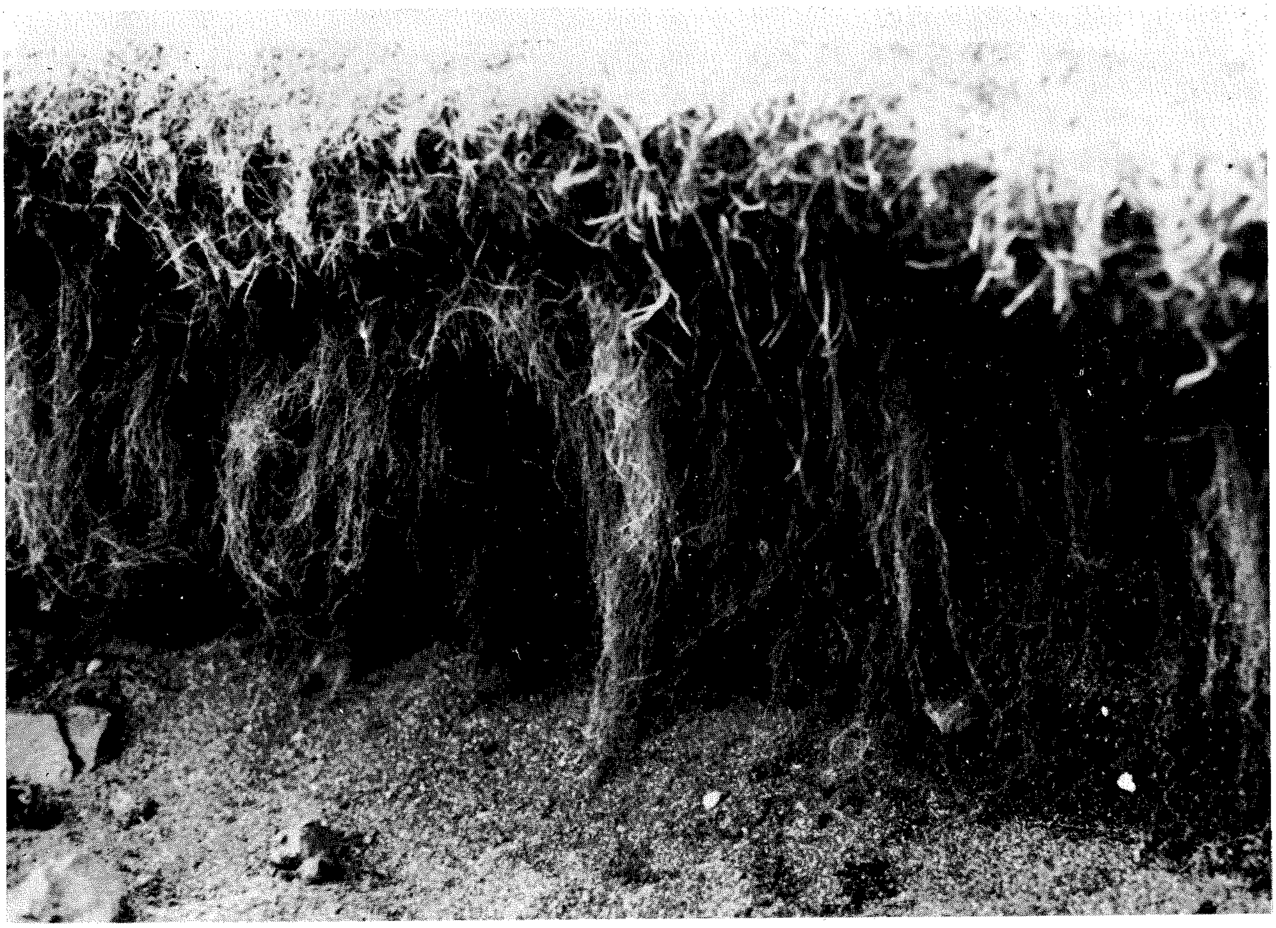
* Marked Forbs on the map and A5 in the species list under dry meadowland community, but should possibly be regarded as a separate community.

B PUFFIN GROUND COMMUNITY

B1 Puffin Ground society	70	13	XVI	XIX	XX	XVII	XVIII
Achillea millefolium	20–1	×	100–1	..	..	×	..
Agrostis tenuis	80–1	..	60–2	..	80–1	100–3	..
Angelica archangelica	..	..	×	..	..	×	60–3
Cerastium fontanum	40–1	×	80–1	..	..	×	..
Euphrasia frigida	..	..	..	..	..	×	..
Festuca rubra	40–1	100–4	..	..	..	100–1	..
Leontodon autumnalis	..	..	..	..	..	×	..
Luzula multiflora	..	..	..	..	..	×	..
Myosotis arvensis	..	..	..	..	..	×	..
Plantago lanceolata	..	..	..	..	..	10–1	..
Poa pratensis	100–2	100–1	100–4	100–4	100–2	..	100–3
Poa trivialis	100–1	..	60–2	..	80–1	90–1	..
Potentilla anserina	100–4	..	..	..	..	×	×
Ranunculus acris	..	×	..	..	..	10–1	80–2
Rumex acetosa	100–2	×	100–3	..	100–3	10–1	100–2
Sedum rosea	×	..	..	..	..	..	..
Stellaria media	100–3	100–1	80–3	100–3	100–3	20–3	100–3
Taraxacum sp.	..	×	..	..	..	10–2	..
Tripleurospermum maritima	..	..	×	60–2	..	..	60–3

C GRAVELLY FLAT COMMUNITY

C1: Gravel with sparse vegetation	1	3	19	82	72	92	46	54	63	
Agrostis stolnifera	..	..	..	..	..	..	×	100—1	60—1	
Agrostis tenuis	..	..	..	..	..	..	..	..	..	0
Alopecurus geniculatus	..	40—1	80—1	..	..	..	..	..	..	
Anthoxanthum odoratum	..	60—1	20—1	100—1	100—1	100—1	80—1	80—1	100—1	
Callunna vulgaris	..	..	..	..	..	60—1	..	..	..	
Carex flacca	..	..	..	..	..	×	..	..	..	
Cardaminopsis petrea	100—1	..	20—1	..	20+	..	40—1	40—1	20—1	
Cerastium alpinum	..	..	..	..	40—1	100—1	..	80—1	40—1	
Cerastium fontanum	20—1	..	×	80—1	..	..	40—1	40—1	60+	
Cystopteris fragilis	..	..	..	..	..	..	..	..	..	0
Empetrum hermafroditum	..	..	..	..	..	80—2	..	..	..	
Epilobium collinum	..	..	..	..	..	..	..	..	..	0
Equisetum arvense	..	..	..	..	..	..	..	20—1	80—1	
Equisetum pratense	..	..	..	..	..	..	..	..	..	0
Euphrasia frigida	..	..	×	..	..	..	..	..	20+	
Festuca rubra	100—1	60—1	40—1	100—1	100—1	100—1	40—1	60—1	60—1	
Festuca vivipara	..	..	..	..	20—1	40—1	20—1	80—1	..	
Galium Normanii	×	..	×	..	..	40—1	..	..	×	
Galium verum	..	..	..	..	..	40—1	..	..	×	
Juncus trifidus	..	..	..	..	..	..	×	..	..	
Kobresia myosuroides	..	..	..	..	..	..	..	..	..	0
Koenigia islandica	..	..	..	..	..	..	..	..	..	0
Lathyrus pratensis	..	..	..	..	..	×	..	..	..	
Luzula multiflora	100—1	..	..	..	..	..	..	..	..	
Luzula spicata	..	..	×	20—1	20—1	100—1	20—1	40—	100—1	
Myosotis arvensis	×	..	..	..	..	..	..	..	..	
Nardus stricta	..	20—1	..	..	..	..	..	..	..	
Oxyria digyna	100—1	..	×	..	..	..	100—1	..	..	
Plantago lanceolata	..	×	×	..	..	..	..	..	..	
Pinguicula vulgaris	..	..	..	..	..	×	..	..	..	
Plantago maritima	100—1	20—1	80—1	..	80—1	20—1	×	..	×	
Poa glauca	20—1	..	..	..	..	..	20—1	..	..	
Poa pratensis	60—1	..	..	..	..	..	..	..	..	
Polygonum viviparum	..	..	..	..	..	..	..	..	..	0
Ranunculus acris	×	..	..	..	..	..	..	..	..	
Rhinanthus minor	..	..	..	..	..	..	..	..	..	0
Rumex acetosa	100—1	20+	×	..	..	..	60—1	..	40—1	
Sagina nodosa	..	..	..	20—1	..	20—1	..	..	..	
Salix herbacea	..	..	..	..	..	20—1	×	..	..	
Saxifraga caespitosa	60—1	..	..	..	..	..	20—1	..	..	
Saxifraga hypnoides	×	..	+	..	..	..	..	..	..	
Sedum rosea	..	..	..	..	..	..	40—1	..	..	
Sedum villosum	×	..	..	..	..	..	..	..	..	
Sieglingia decumbens	..	..	..	..	..	..	..	..	..	0
Silene acaulis	80—1	..	×	100—1	20—1	100—1	20—1	80—1	×	
Silena maritima	..	80—1	60—1	100—1	100—1	×	20—1	30—1	100—1	
Stellaria media	..	..	..	..	..	..	..	..	..	0
Succisa pratensis	..	..	..	..	..	..	..	..	..	0
Taraxacum sp.	..	..	..	..	..	..	..	..	..	0
Thymus Drucei	20—1	..	40—1	80—1	80—1	100—1	×	60—1	100—1	
Tripleurospermum maritima	..	..	..	..	..	..	..	..	..	0



The gravelly flat community: Erosion of the dry meadowland. Height of the top layer about 60 cm. Photo by S. Magnússon.

C2	24	36	45	49	51
Achillea millefolium	×	..	..	..	20–1
Agrostis stolonifera	..	..	80–1	100–1	100–1
Anthoxanthum odoratum	40–1	..	..	..	..
Armeria maritima	80–1	80–1	80–1	60–1	60–1
Cardaminopsis petrea	×	..	40–1	..	×
Carex flacca	..	..	..	..	20–1
Cerastium alpinum	100–1	80–1	100–1	100–1	60–1
Cerastium fontanum	60–1	..	..	60–1	60–1
Draba incana	×	..	..	..	..
Empetrum hermafroditum	×	..	×	40–1	40–1
Equisetum arvense	..	80–1	×	..	..
Equisetum pratense	..	..	..	80–1	..
Euphrasia frigida	..	..	×	..	..
Festuca rubra	..	..	20–1	..	60–1
Festuca vivipara	100–2	100–1	100–2	100–2	100–2
Galium Normanii	40–1	..	20–1	60–1	60–1
Kobresia myosuroides	..	..	..	..	20–1
Leontodon autumnalis	×	..	..	..	..
Luzula multiflora	60–1	..	..	..	20–1
Luzula spicata	100–2	100–1	80–1	100–1	100–1
Oxyria digyna	..	..	80–1	×	..
Parnasia palustris	..	..	×	..	..
Pinguicula vulgaris	40–1	..	..	..	..
Plantago maritima	×	..	×	20–1	..
Poa pratensis	..	..	40–1	..	..
Polygonum aviculare	..	..	40–1	×	..
Polygonum viviparum	100–1	..	×	100–1	100–1
Ranunculus acris	×	..	..	..	..
Rhinanthus minor	20–1	..	..	..	..
Rumex acetosa	80–1	80–1	40–1	..	80–1
Sagina nodosa	..	..	×	..	..
Salix herbacea	100–2	..	20–1	80–1	80–1
Saxifraga caespitosa	..	..	80–1	×	..
Saxifraga hypnoides	60–1	..	..	..	20–1
Sedum rosea	..	..	×	..	..
Sedum villosum	60–1	20–1	40–1	40–1	40–1
Selaginella selaginoides	20–1	..	..	..	..
Silene acaulis	60–1	×	60–1	80–1	80–1
Silene maritima	..	..	..	..	..
Stellaria media	..	..	×	×	..
Thalictrum alpinum	..	..	..	..	20–1
Thymus Drucei	..	..	..	..	..

This society C2 seems to constitute a sort of intermediate stage between gravelly flat in its typical form as in C1 and the heath vegetation J1 and 2. Thus there are species occurring such as *Galium verum* and *Polygonum viviparum, Salix herbacea* and *Achillea millifolium,* which do not regularly grow on gravelly flats.

C3	7	25	31	33
Agrostis stolonifera	100–2	100–1	80–1	100–1
Armeria maritima	100–1	100–1	60–1	100–1
Cardaminopsis petrea	×	..	..	..
Cerastium alpinum	..	..	..	60–1
Cerastium fontanum	..	..	20–1	..
Elymus arenarius	×	..	..	..
Equisetum arvense	..	..	40–1	×
Festuca rubra	..	20–1	..	20–1
Plantago lanceolata	×	..	..	..
Plantago maritima	40–1	20–1	..	..
Rumex acetosa	×	..	..	×
Sagina nodosa	..	..	..	20–1
Silene acaulis	..	..	..	×
Silene maritima	×	60–1	20–1	×
Tripleurospermum maritima	×	..	..	..

This society C3 seems to constitute a sort of intermediate stage between a grass community and a gravelly flat community, as in C1. The species are fewer, but the frequency and the cover of *Agrostis stolonifera* and *Armeria maritima* may be greater.

THE HEATH VEGETATION

Where the soil is very dry, the heath vegetation gradually takes over the dry meadowland. The heath vegetation can either be found in slopes or flat land. Mostly it is found in the old lava covering the mid-west part of the island and also on the top of the mountaines.

The characteristics of the heath vegetation are mainly: High coverage of *Empetrum hermafroditum* and/or *Salix herbacea* and the division between societies is partly based on that. Also characteristic is high coverage of mosses (*Racomitrium* sp. in the lava) and the existence of *Kobresia myosuroides* and *Luzula multiflora* and *L. spicata.*

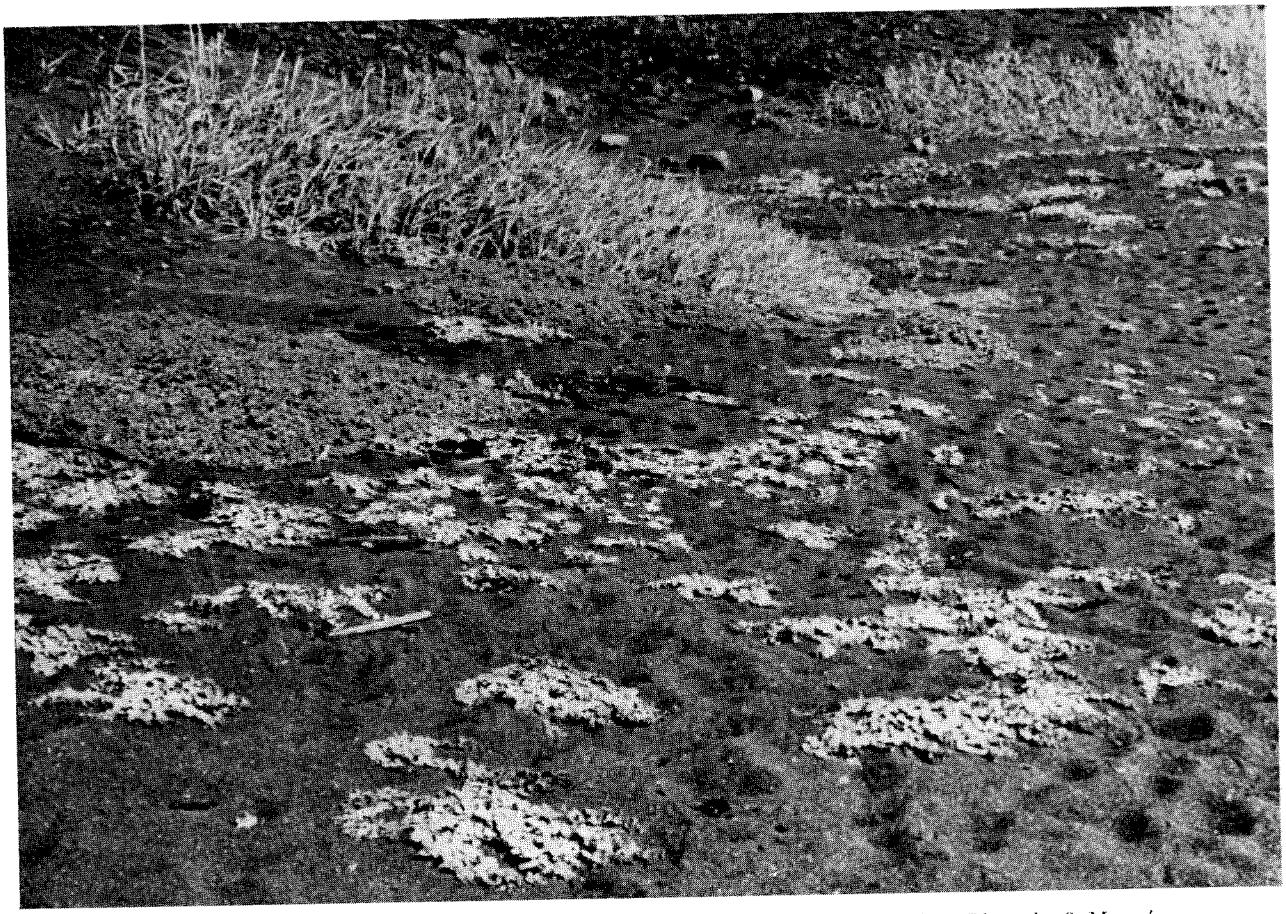
J 1 *Empetrum hermafroditum* society and J 2 *Salix herbacea* society are in many ways similar, of like composition and, in fact, often merge into one another. *Salix herbacea,* however, is more to be found on flat land and its productivity is greater than in the *Empetrum* society, where the vegetation is frequently less dense.

J HEATH VEGETATION

J1: Empetrum hermafroditum society

	17	26	55	61	64
Agrostis tenuis	..	..	..	..	..
Agrostis stolonifera	60–1	..	×	..	60–1
Alchemilla alpina	..	..	..	..	..
Alchemilla vestita	..	..	..	..	..
Anthoxanthum odoratum	×	80–1	100–1	100–2	40–1
Armeria maritima	..	×	×	..	..
Armeria vulgaris	100–1	..	..	..	..
Botrychium lunaria	..	20–1	..	×	×
Calluna vulgaris	..	..	100–2	..	..
Cardaminopsis petrea	..	..	×	..	..
Carex capillaris	..	..	..	×	..
Carex flacca	..	100–1	20–1	100–1	..
Carex rariflora	..	..	..	..	..
Cerastium alpinum	..	×	×	..	..
Cerastium fontanum	100–1	20–1	60–1	..	..
Coeloglossum viride	..	..	20–1	40–+	40+
Empetrum hermafroditum	100–2	100–2	100–4	100–3	100–3
Equisetum arvense	80–1	..	..	..	..
Erigeron boreale	..	..	×	60–1	..
Euphrasia frigida	..	..	..	×	..
Festuca rubra	100–2	100–2	..	..	60–1
Festuca vivipara	..	100–3	100–2	100–2	100–2
Galium Normanii	80–1	80–1	..	..	..
Galium verum	..	80–1	100–1	20–1	20–1
Gentianella campestris	..	..	..	80–1	60–+
Juncus bufonius	..	..	..	×	..
Juncus trifidus	..	..	×	..	40–1
Kobresia myosuroides	..	..	..	..	20–1
Luzula multiflora	100–1	100–1	100–1	100–1	20–1
Luzula spicata	80–1	20–1	80–1	..	80–1
Myosotis arvensis	..	×	..	..	..
Parnassia palustris	..	..	..	40–1	..
Pinguicula vulgaris	..	×	80–1	..	×
Plantago maritima	80–1	60–1	20–1	..	..
Poa pratensis	..	..	20–1	100–1	..
Polygonum viviparum	100–1	80–1	100–1	100–1	100–1
Prunella vulgaris	..	..	..	..	..
Ranunculus acris	..	×	..	..	..
Rhinanthus minor	×	20–1	20–1	..	×
Rubus saxatilis	..	×	..	..	×
Salix herbacea	100–1	60–1	20–1	60–1	100–1
Saxifraga caespitosa	..	..	×	..	..
Selaginella selaginoides	..	20–1	..	..	20–1
Silene acaulis	80–1	×	×	..	..
Succisa pratensis	..	..	..	..	..
Taraxacum sp.	..	×	..	..	..
Thymus Drucei	100–1	100–1	100–2	100–2	100–1
Trifolium repens	..	20–1	..	..	..
Trisetum spicatum	..	..	..	..	..
Veronica officinalis	..	..	×	..	..
Filipendula ulmaria	×	..	..	..	..
Rumex acetosa	..	×	..	..	..

J2: Salix herbacea society	52	74	80
Achillea millefolium	..	40–1	..
Agrostis stolonifera	100–1	60–1	..
Anthoxanthum odoratum	60–1	..	80–1
Armeria maritima	..	..	..
Botryhium lunaria	..	..	..
Calluna vulgaris	..	..	60–1
Carex flacca	×	..	..
Cerastium alpinum	..	..	40–1
Cerastium fontanum	100–1	60–1	40–1
Empetrum hermafroditum	100–1	80–1	..
Equisetum arvense	100–2	..	..
Erigeron boreale	..	40+	..



Sand beach community: *Elymus arenarius, Minuartia peploides* and *Mertensia maritima.* Photo by S. Magnússon.

Euphrasia frigida	×	20—1	..
Festuca rubra	100—2	80—1	100—3
Festuca vivipara	60—1	60—1	..
Galium Normanii	..	60—1	..
Galium verum	100—1	100—1	20—1
Gentianella amarella	..	20—1	..
Gentianella campestris	60—1	..	..
Juncus trifidus	..	20—1	..
Kobresia myosuroides	..	100—1	..
Leontodon autumnalis	..	40—+	..
Luzula multiflora	100—1	20—1	..
Luzula spicata	..	..	80—1
Myosotis arvensis	..	20—1	..
Parnassia palustris	..	40—1	..
Plantago maritima	..	60—1	60—1
Poa pratensis	100—1	..	..
Polygonum viviparum	100—1	100—1	100—2
Ranunculus acris	..	60—1	40—1
Rhinanthus minor	..	40—1	..
Rumex acetosa	..	..	80—1
Salix herbacea	100—2	100—3	100—2
Selagenella selaginoides	..	60—3	..
Silene acaulis	..	20—1	100—2
Succisa pratensis	..	80—1	..
Taraxacum sp.	..	60—1	..
Thalictrum alpinum	..	80—1	..
Thymus Drucei	100—1	100—1	40—1

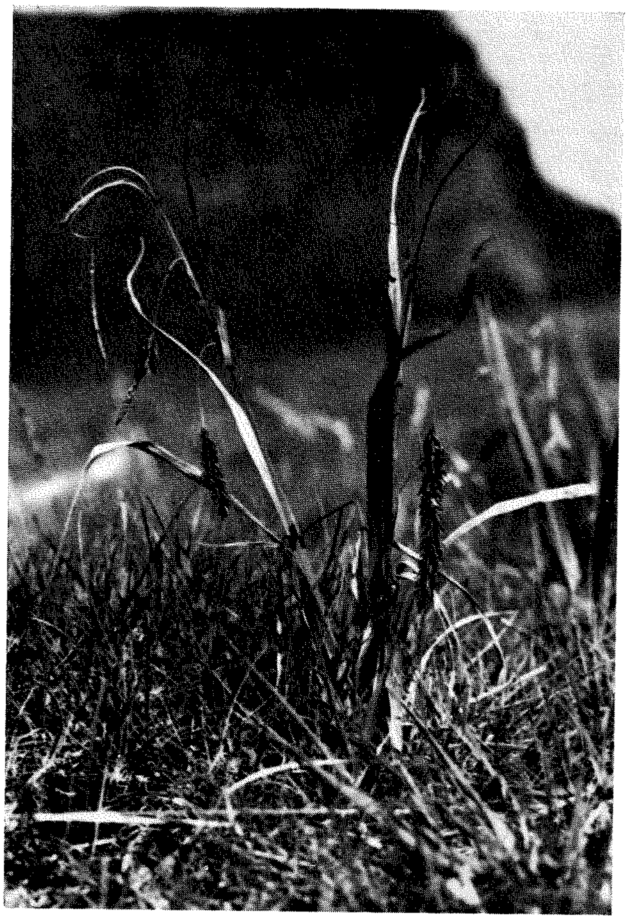
THE SAND BEACH COMMUNITY

It is difficult to use any normal measurements for the vegetation in these areas, because of the very uneven distribution of the plants. Near the sea, about 5 metres from high tide mark, may be seen the first wisps of *Minuartia peploides* and *Mertensia maritima. Minuartia* forms larger wisps than *Mertensia,* and in some place quite shapely hummocks. A little higher up, and among the hummocks, grows *Cakile maritima.* Still higher up are dunes, in which are found: *Elymus arenarius, Festuca rubra, Plantago maritima, Cakile maritima, Mertensia maritima, Angelica archangelica, Silene maritima, Potentilla anserina* and *Tripleurospermum maritima.*

Sand beach is found chiefly in two places, i.e., at Thraelaeidi en route to Heimaklettur, and at Klaufin beside the isthmus on Stórhöfdi.

THE BOG COMMUNITY

Hardly any bogs are to be found in the Westman Islands. There are two small patches in Herjólfsdalur near the sea, where traces of bog can be discerned. It would seem that water collects here. It is difficult to estimate the size of this bog because it gradually merges with the sur-



Bog community: *Carex lyngbyei.* Photo by S. Magnússon.

E BOG VEGETATION	Upper	Lower
Agrostis tenuis	20.3	60.3
Alopecurus aquatis	..	100—2
Anthoxanthum odoratum	20—1	100—2
Armeria maritima	..	40—1
Carex flacca	..	60—1
Carex Lyngbyei	70—4	..
Carex maritima	..	20—1
Carex nigra	20—2	..
Eleocharis uniglumis	90—3	..
Equisetum arvense	70—1	40—2
Equisetum palustris	10—2	60—2
Eriophorum angustifolium	..	20—4
Eriophorum Scheuchzeri	..	×
Euphrasia frigida	..	20—1
Festuca rubra	..	80—1
Juncus articulatus	..	×
Leontodon autumnalis	30—1	40—1
Parnassia palustris	×	100—1
Poa pratensis	30—1	60—2
Potentilla anserina	50—1	..
Puccinellia maritima	..	×
Puccinellia retroflexa	..	×
Ranunculus acris	30—1	..
Rhinanthus minor	20—1	40—1
Rumex acetosa	30—1	..
Taraxacum sp.	20—2	..
Triglochin palustre	..	60—1

rounding vegetation. The uppermost patch was more typical and larger, and the water level higher. The patches were quite separated from each other by a strip of grass.

The following Table shows that the composition of the vegetation of the patches varies considerably, and there is a bigger variety of species in the lower patch.

A cross section of the lower patch right across its middle was taken, and observations were made at 50 cm intervals. The transect reached into the grass on each side.

THE CLIFF COMMUNITY

Cliffs encircle most of the island. In the north are Heimaklettur, Midklettur and Yztiklettur. West of the town are Klifid, Háin and Dalfjall.

In all these cliffs, and in many other places, birds breed in great numbers, especially the fulmar and the kittiwake. In the nesting grounds and around it a large amount of bird droppings clearly have a great influence on the composition of the vegetation. Where there is little bird dropping, the following species grow: *Armeria maritima, Cerastium alpinum, Cerastium fontanum, Cochlearia officinalis, Cystopteris fragilis, Draba incana, Oxyria digyna, Polypodium vulgare, Sagina nodosa, Sedum rosea* and *Saxifraga caespitosa.*

There is a clear affinity here with the gravelly flat vegetation, where all the above-mentioned species also grow.

Beneath those areas in the cliffs where there is an inward slope or there are for other reasons no bird droppings, there is here and there quite a broad belt, about 1 meter, of *Atriplex glabriuscula.*

On the ledges and under the cliffs there is, as stated above, a large amount of bird droppings. In many of these habitats are found *Angelica archangelica,* together with *Festuca rubra, Festuca vivipara, Ranunculus acris, Rumex acetosa* and *Tripleurospermum maritima.* On the edges and in the clefts of the cliffs *Sedum rosea* is often found to be dominating species.

In other places, though not in any specific ones, the following species were also found: *Agrostis canina, Euphrasia frigida, Galium Normanii,* *Hieracium* sp., *Plantago lanceolata, Poa glauca, Poa trivialis, Sagina procumbens, Sedum acre, Silene acaulis, Silene maritima, Stellaria media, Taraxacum* sp. and *Thymus Drucei.*

DISCUSSION

The vegetation on Heimaey shows much sign of trampling and encroachment by animals, so that a natural composition of vegetation is hardly to be found except on the cliffs.

Many species, which have been found either on cultivated land or in the town, or where the ground cover has been disturbed by man, may not be listed in the tables describing the societies. These were, however, recorded and are listed in the following table.

In the town there are, for instance, patches of *Matricaria matricarioides, Poa annua, Lolium perenne* and other species. Above the Fridarhöfn was a large area mostly covered with *Urtica urens* and *Euphrasia frigida.* Various other plants were found in the vicinity of the harbour. Plants cultivated in gardens or which grew in rubbish dumps are not included in the lists of plants.

ACKNOWLEDGEMENTS

The authors are very grateful to Dr. Sigurdur Jónsson and his wife, Dr. Gisele Jónsson, from Paris for their encouragement and assistance in many ways. Thanks are also due to the Icelandic Meteorological Office and the Icelandic Institute of Natural History.

The work on which this paper is based was sponsored by the Surtsey Research Society with grant from the U.S. Atomic Energy Commission, Environmental Branch, under the contract No. AT (30—1)—3549.

Bog community: Cross section taken. Photo by S. Magnússon.

References:

Fridriksson, Sturla and Johnsen, Björn, 1967: The vascular Flora of the Outer Westman Islands, Greinar IV, 3, Societas Scientiarum Islandica.

Fridriksson, Sturla; Bjarnason, A. H., and Sveinbjörnsson, B, 1971: On the Vegetation of Heimaey, Surtsey Research Progress Report VI.

Hylander, Nils, 1955: Förteckning över Nordens växter, I. Kärlväxter (List of plants of N.V. Europe, I. Vascular Plants), Lund, Sweden.

Johnsen, Baldur, 1939: Observations on the vegetation of the Westman Islands, Societas Scientiarum Islandica, Vol. XXII.

Löve, Áskell, 1970: Íslenzk ferðaflóra, Almenna bókafélagid, Reykjavík.

Sjörs, Hugo, 1960: Nordisk växtgeografi, Stockholm, Sweden.

A TRANSECT ACROSS THE LOWER BOG AT 50 CM INTERVALS FROM NW TO SE

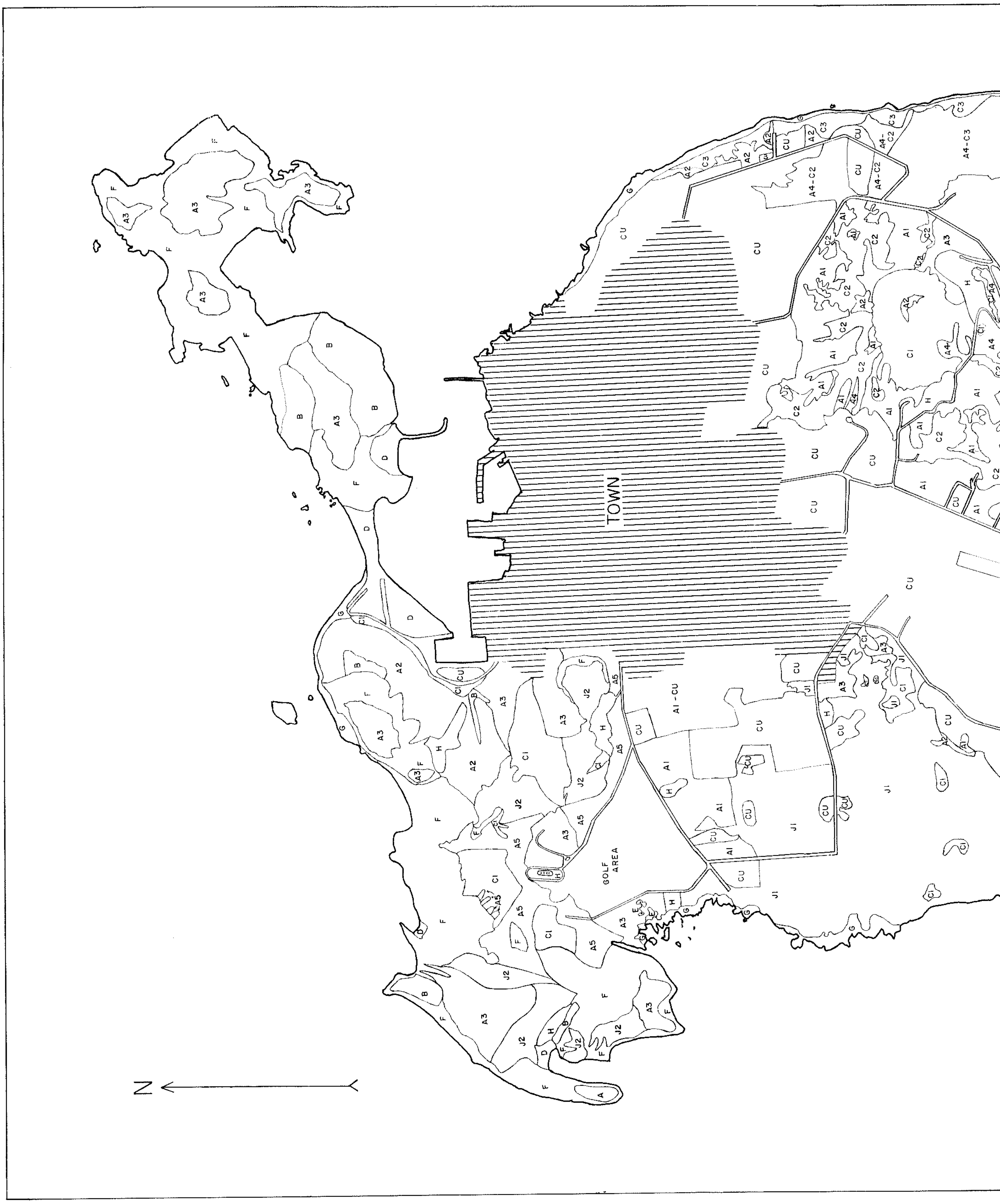
	1		2		3		4		5		6		7		8		9		10		11		12		13	m
Agrostis tenuis																						×				
Anthoxanthum odoratum									×																	
Armeria maritima							×																			
Carex maritima											×				×		×									
Equisetum arvense	×			×						×																
Equisetum palustre																		×								
Festuca rubra													×						×							
Poa pratensis		×										×														
Puccinellia maritima								×															×			
Puccinellia retroflexa				×		×																		×	×	
Triglochin palustre					×	×												×	×	×						
A stone														×							×					

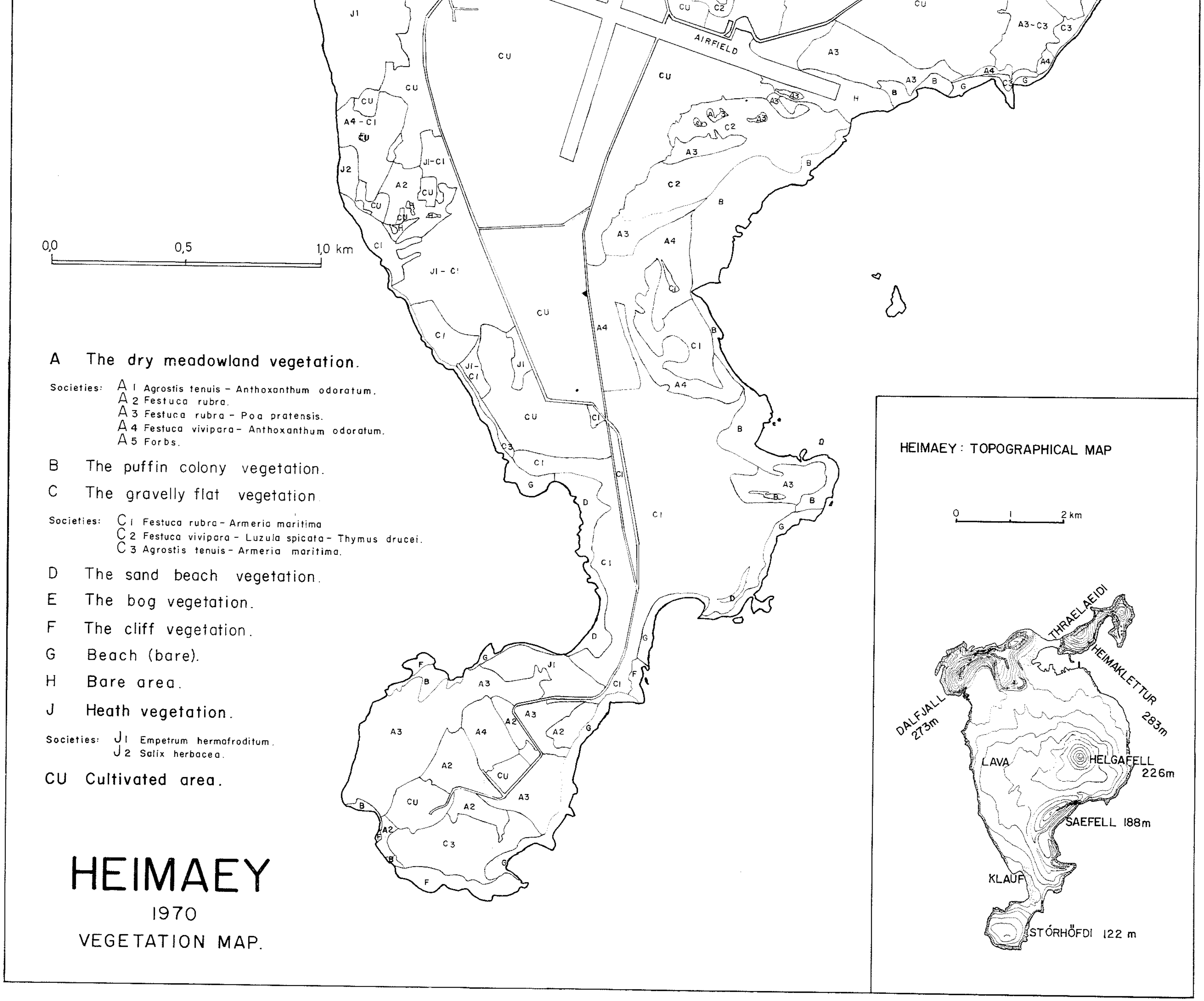
LIST OF PLANTS FROM HEIMAEY

(Nomenclature according to *Hylander, Nils* (1955).

Achillea millefolium
Agrostis canina
Agrostis stolonifera
Agrostis tenuis
Alchemilla alpina
Alchemilla sp.
Alopecurus aequalis
Alopecurus geniculatus
Angelica archangelica
Anthoxanthum odoratum
Armeria maritima
Atriplex glabriuscula
**Avenochloa pubescens*
Bartsia alpina
Botrychium lunaria
**Bromus inermis*
Cakile maritima
Calluna vulgaris
Capsella bursa-pastoris
Cardamine hirsuta
Cardamine pratensis
Cardaminopsis petrea
Carex capillaris
Carex flacca
Carex Lyngbyei
Carex maritima
Carex nigra
Carex rariflora
Cerastium alpinum
Cerastium cerastoides
Cerastium fontanum
**Chenopodium album*
Cirsium arvense
Coeloglossum viride
Cystopteris fragilis
Dactylis glomerata
Draba incana
Deschampsia caespitosa
Eleocharis uniglumis
Elymus arenarius
Empetrum hermafroditum
Epilobium collinum
Equisetum arvense
Equisetum palustre
Equisetum pratense
Erigeron boreale
Eriophorum angustifolium
Eriophorum Scheuchzeri
Euphrasia frigida
**Festuca rubra*
Festuca vivipara
Filipendula ulmaria
Galium Normanii
Galium verum
Gentianella amarella
Gentianella aurea
Gentianella campestris
Gnaphalium uliginosum
**Hieracium* sp.
Juncus articulatus
Juncus bufonius
Juncus trifidus
Kobresia myosuroides
Koenigia islandica
Lathyrus maritimus
Lathyrus pratensis
Leontodon autumnalis
Linum catharticum
**Lolium perenne*
Luzula multiflora
Luzula spicata
Matricaria matricarioides
Mertensia maritima
Minuartia peploides
Myosotis arvensis
Oxyria digyna
Parnassia palustris
Phleum pratense
Pinguicula vulgaris
Plantago lanceolata
Plantago maritima
Poa annua
Poa glauca
Poa pratensis
Poa trivialis
Polygonum aviculare
Polygonum viviparum
Polypodium vulagre
Potentilla anserina
Potentilla crantzii
Prunella vulgaris
Puccinellia maritima
Puccinellia retroflexa
Ranunculus acris
Ranunculus repens
**Rhinantus minor*
Rubus saxatilis
Rumex acetosa
Rumex acetosella
Rumex longifolius
Sagina nodosa
Sagina procumbens
Salix herbacea
Saxifraga caespitosa
Saxifraga hypnoides
Saxifraga nivalis
Sedum acre
Sedum rosea
Sedum villosum
Selaginella selaginoides
Senecio vulgaris
Sieglingia decumbens
Silene acaulis
Silene maritima
Spergula arvensis
Stellaria media
Succisa pratensis
Taraxacum sp.
Thalictrum alpinum
Thymus Drucei
Trifolium repens
Triglochin palustre
Tripleurospermum maritima
Trisetum spicatum
Urtica urens
Veronica officinalis
Viccia cracca
Viccia sepium
Viola canina

**Löve, Áskell* (1970):
Íslenzk ferðaflóra,
Reykjavík, 1970.
Two to three species of Hieracium were found with certainty.


TOWN
GOLF AREA
N


HEIMAEY
1970
VEGETATION MAP.
A The dry meadowland vegetation.
Societies: A 1 Agrostis tenuis - Anthoxanthum odoratum.
A 2 Festuca rubra.
A 3 Festuca rubra - Poa pratensis.
A 4 Festuca vivipara - Anthoxanthum odoratum.
A 5 Forbs.
B The puffin colony vegetation.
C The gravelly flat vegetation.
Societies: C 1 Festuca rubra - Armeria maritima
C 2 Festuca vivipara - Luzula spicata - Thymus drucei.
C 3 Agrostis tenuis - Armeria maritima.
D The sand beach vegetation.
E The bog vegetation.
F The cliff vegetation.
G Beach (bare).
H Bare area.
J Heath vegetation.
Societies: J1 Empetrum hermafroditum.
J2 Salix herbacea.
CU Cultivated area.
0,0 0,5 1,0 km
AIRFIELD
HEIMAEY: TOPOGRAPHICAL MAP
0 1 2 km
THRAELAEIDI
HEIMAKLETTUR 283m
DALFJALL 273m
LAVA
HELGAFELL 226m
SAEFELL 188m
KLAUF
STÓRHÖFDI 122 m

Vegetation on Surtsey — Summer 1970

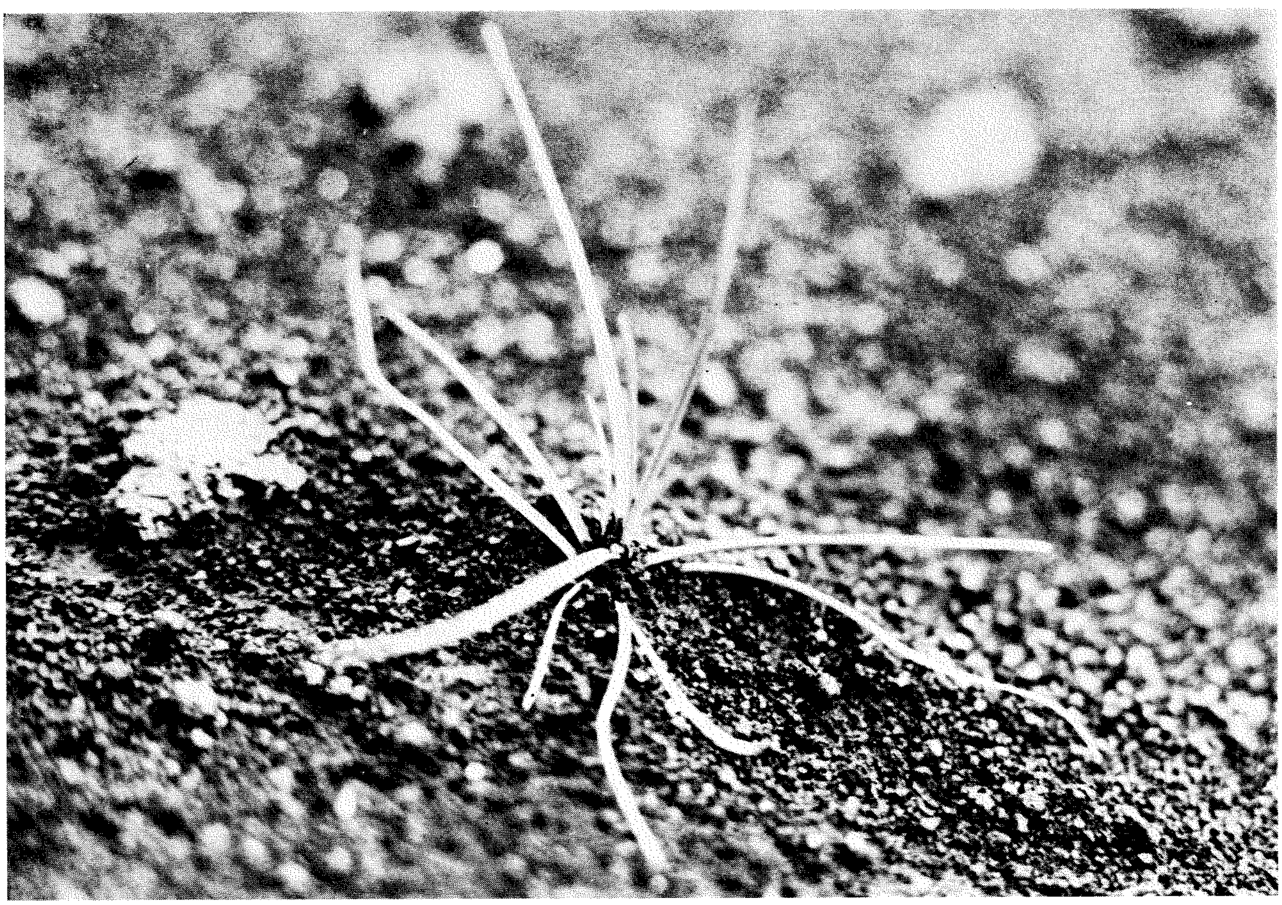
By
STURLA FRIDRIKSSON*, BJARTMAR SVEINBJÖRNSSON
and SKÚLI MAGNÚSSON
* The Agricultural Research Institute, Reykjavík, Iceland

METHOD OF INVESIGATION

In the summer of 1970, the studies of vegetation on the island of Surtsey, were conducted in a way similar to those of preceding summers. Two students, B. Sveinbjörnsson and S. Magnússon, kept the plants that were found under regular observation, while continuing to look for new ones. Each plant was marked with a numbered peg, where it was found and its length in cm, together with the number of branches and leaves was recorded. Similar studies were carried out on a number of occasions throughout the entire period. Part of these results is shown in *Table 1*.

DESCRIPTION OF VEGETATION

In the beginning each plant was marked on an aerial photograph of the island. Later their exact



Elymus arenarius.

TABLE 1
VASCULAR PLANTS ON SURTSEY IN 1970

No:	NAME OF SPECIES:	Location	Plant from 69	Date of first observation	No. of branches	No. of leaves	Date of last observation	No. of branches	No. of leaves	Maximum length in cm	Remarks
1	*Honckenya peploides*	F-13	x	17.6	1	8	20.8	3	32	2	
2	— —	J-18	x	17.6	4	36	20.8	5	101	10	
3	— —	R-17	x	16.6	5	74	25.8	8	126	16	
4	— —	J-18		20.6	1	6	20.8	1	10	1	
5	— —	F-13		17.6	1	4	20.8	1	16	2	
6	— —	I-18	x	17.6	6	82	20.8	8	161	9	
7	— —	M-15		20.6	1	6	20.8	1	12	1	
8	— —	M-15		20.6	1	2	8.7	disappeared			
9	— —	J-18	x	16.6	2	39	20.8	8	137	6	
10	*Cochlearia officinalis*	L-17		18.6		17	20.8		18		
12	— —	L-17		18.6		23	20.8		12		
13	*Honckenya peploides*	K-18	x	16.6	2	24	20.8	14	262	13	
14	— —	K-17	x	16.6	1	8	20.8	7	128	10	
15	— —		x	16.6	6	44	20.8	6	116	3	
16	— —	J-18	x	17.6	1	12	20.8	4	56	3.5	
17	— —	J-18	x	17.6	7	86	20.8	11	175	8	
18	*Cochlearia officinalis*	J-18		9.7		9					
19	— —	N-6		3.8		6	27.8		7		
20	*Honckenya peploides*	J-18		16.6	2	18	20.8	2	36	3.5	
21	— —	J-18	x	16.6	4	30	20.8	2	34	4	
23	— —	J-18	x	16.6	4	26	20.8	3	54	3.5	
24	— —	J-18	x	16.6	2	12	20.8	2	34	2.5	
25	— —	J-17		16.6	1	6	20.8	1	12	1.5	
26	— —	J-17	x	16.6	3	22	20.8	5	76	5	
27	— —	J-17	x	16.6	1	6	20.8	2	16	1.5	
28	— —	E-12		9.7	1	4	20.8	1	6	0.5	
29	*Cochlearia officinalis*	K-18		16.7		38					8 plants observed**
30	*Honckenya peploides*	J-18		22.6	1	10	20.8	1	16	1.5	
31	*Cochlearia officinalis*	K-18		22.6		13	20.8		33		
32	*Honckenya peploides*	E-12	x	20.6	1	8	20.8	1	14	3.5	
33	— —	J-18	x	9.7	3	24	20.8	3	38	4	
34	— —	E-15		9.7	1	6	21.8	1	6	0.5	
35	— —	E-12		16.7	1	8	20.8	3	24	1.5	
36	— —	E-13	x	17.7	1	9	20.8	1	17	2.5	
37	— —	D-12		17.7	3	37	20.8	3	47	4	
38	— —	E-11		17.7	1	5	20.8	1	4	0.7	
39	— —	G-13		14.7	1	8	20.8	1	16	2.2	
40	— —	E-12		9.7	1	8	20.8	2	14	1.5	
41	— —	E-12		17.7	1	6	20.8	1	8	2.5*	
42	— —	F-13		9.7	1	20	20.8	2	26	1.5	
43	— —	E-12		17.7	1	6	20.8	1	6	0.5	
44	— —	E-11		17.7	1	4	20.8	1	4	0.5	
45	— —	E-12		17.7	1	6	20.8	1	6	2.5*	
46	— —	E-12		17.7	1	6	20.8	1	8	0.5	
47	— —	E-11		17.7	1	6	20.8	1	8	0.5	
48	— —	E-11		17.7	1	6	20.8	1	12	0.5	
49	— —	E-11		17.7	1	6	20.8	1	10	1	
50	— —	E-12		3.8	1	7	20.8	1	6	2*	
51	— —	E-12		3.8	1	9	20.9	1	9	3.15*	
52	— —	E-12		3.8	1	10	20.8	1	8	1	
53	— —	E-12		3.8	1	8	20.8	1	8	0.7	
54	— —	E-12		3.8	1	6	20.8	1	6	2*	
55	— —	E-11		3.8	1	6	20.8	1	6	0.5	
56	— —	E-11		3.8	2	14	20.8	1	16	1.5	
57	— —	E-11		3.8	1	4	20.8	1	4	1.5*	
58	— —	E-14		3.8	2	16	20.8	2	20	2	
59	— —	F-13		20.8	1	8				0.5	
60	— —	F-13		20.8	1	10				1	
61	— —	F-15		20.8	13	176				7	
62	— —	E-15		20.3	1	8				0.5	
63	— —	E-15		20.8	1	12				1	
64	— —	J-18		20.8	4	14				2	
65	*Elymus arenarius*	L-12		20.8	4	19					
66	*Honckenya peploides*	E-11		20.8	1	6				0.5	
67	— —	D-14		21.8	1	16				1.5	
68	— —	F-13		21.8	1	12				1.5	
69	— —	E-14		21.8	1	17				3.5*	
70	*Elymus arenarius*	M-12		21.8		1				5	
71	— —	M-12		21.8		7				9	
72	— —	M-12		21.8		12				6	
73	*Stellaria media*	S-14		25.8		80				10	4 plants
74	*Cochlearia officinalis*	S-14		25.8		25					
75	*Honckenya peploides*	E-12		27.8	1	10				1.5	

* A part of the root was exposed, and measured with the stem.
** Sixteen *Cochlearia officinalis* plants were unmarked.

location was measured, from which a map was drawn. The relative positions of individual plants can be seen on the attached map. Altogether, 101 plants of four vascular species were found. These were classified as follows:

Cochlearia officinalis	30	plants
Elymus arenarius	4	—
Honckenya peploides	63	—
Stellaria media	4	—
	101	

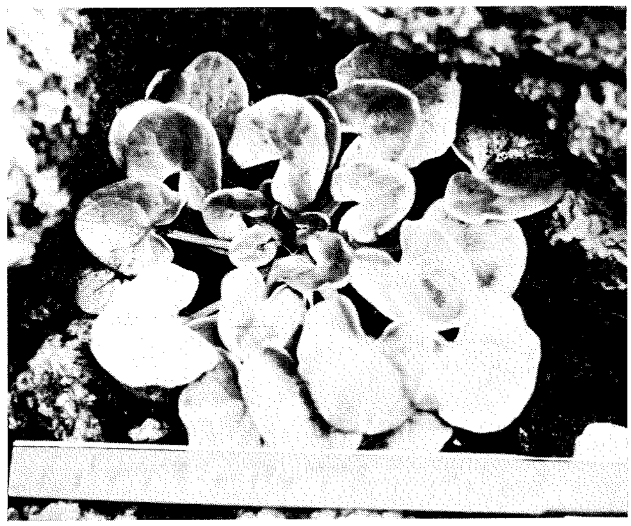
Honckenya peploides: As in the summer of 1969, *Honckenya peploides* was in the summer of 1970 the most widespread plant. It seems to have obtained a fairly firm foothold on the island, for it is known that 18 of these 63 plants survived the winter of 1969—70, and 14 of them were three years old during 1970. Fifteen of these eighteen plants are in the lava in the eastern part of the island (cf. Table 1).

If the attached distribution map is compared with corresponding maps from previous reports, the most striking feature is the lack of all vegatation in the extreme north of the northern part of the island, in plots B and C. The reason is probably that the lagoon that was there has now dried up and the sea can no longer flow into it. It is also interesting to note the large numbers of plants around Pálsbaer. Only *Honckenya* plants grow in the northern part. Plants of other species all grow in the lava. An isolated *Honckenya* plant was found in plot I—4. None of these 63 plants of the *Honckenya* species succeeded in flowering in the summer of 1970.

Cochlearia officinalis: Though the number of this species is quoted as 30 plants, only 7 of them are marked in Table 1 by numbers. The reason is that beside plastic containers full of rainwater that had been installed for research purposes, there grew up 24 very small and feeble *Cochlearia* plants, which had evidently been brought by birds alighting at this artificial water supply. Beside one of the containers there were 8 of these plants (marked peg no. 29), and beside the other 16 unmarked plants. The plants grew in very thin substrate and throve very badly. The remaining 6 plants were much stronger and bigger. Four of these, nos. 18, 19, 31 and 74 did not grow near the containers.

Beside plant no 19 there were some remains of halfeaten bird carrion, feathers and droppings. Beside plant no. 74 were also feathers, bird

Stellaria media.



Cochlearia officinalis. Plant no. 74. (Photo by S. Magnusson.)

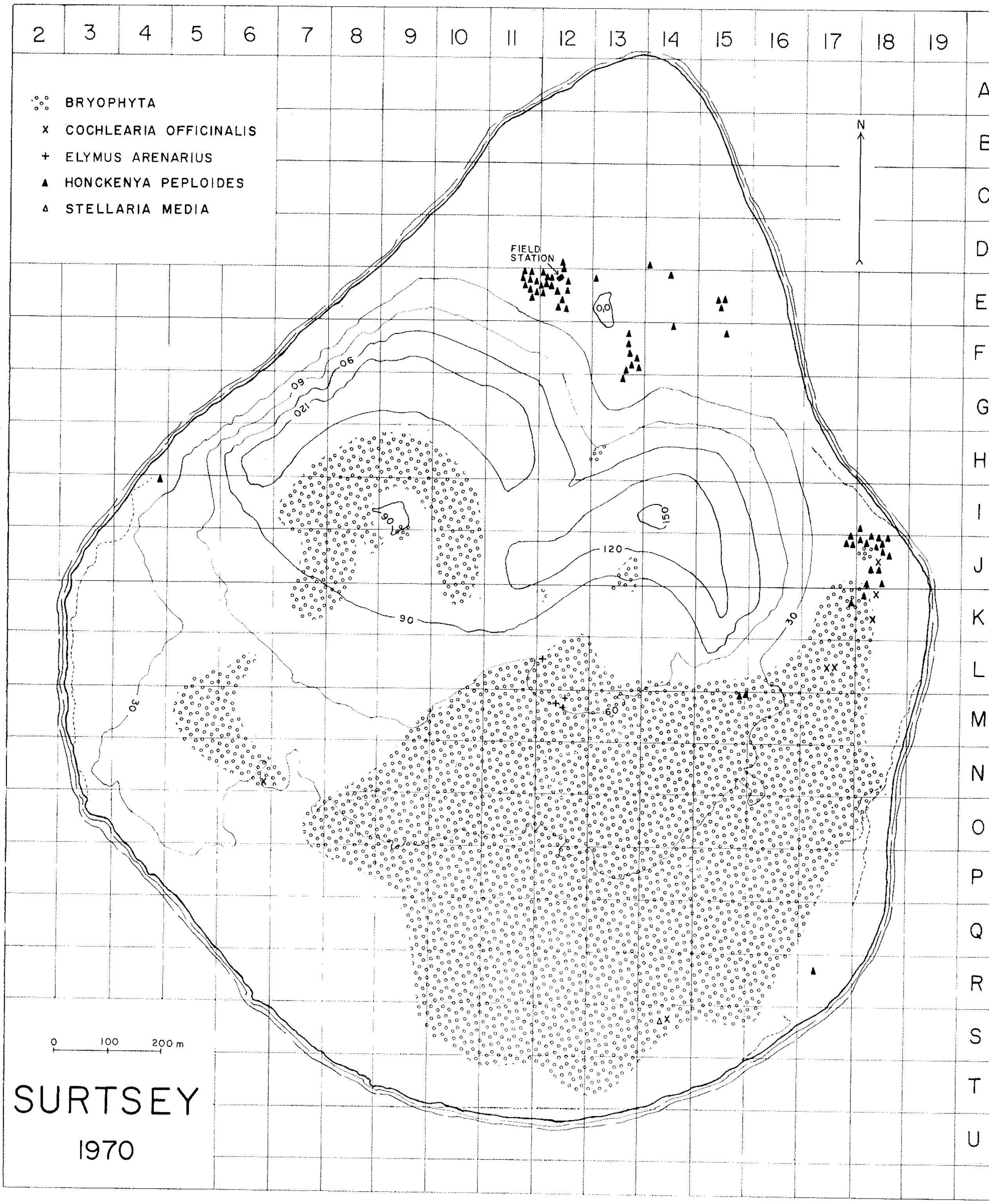
droppings and shell fragments, so that it is almost certain that these plants had been brought by birds.

Of the *Cochlearia* plants, plant no. 74 was the biggest and strongest (see picture). When it was found it had 25 leaves. Twenty of these were 4 cm or more in diameter, and the remainder 2.5 cm in diameter.

Elymus arenarius: On 20th and 21st August, four plants of this grass species, which had been discovered shortly before, were marked. They were growing in driftsand to the west of Surtur I. Plant no. 65 was growing just west of the crater, and the other three 100 metres to the south.

Number 71 had wilted, only one leaf of seven being alive. The others seemed to be in a healthy state. No signs of flowering were observed in any of these plants.

Stellaria media: On August 25th, the first plant



of this species was found on Surtsey. But, a closer observation revealed that there were in fact four plants growing in a compact bunch. They were all marked by one peg no. 73. The plants were 6 meters apart from plant no. 74. Around them were fragments of shells, bird droppings and feathers. The plants appeared to have grown up from the droppings in a small hollow in the lava. The substrate there was only some sand in cracks and hollows. It is almost certain that the plants, like no. 74, were brought by birds.

These plants had flowered and matured seed when they were found. Two of them were mostly withered, but the other two were quite alive. Altogether there were 12 fruits on the plants. Two of them were not fully ripe, but others had already dehisced seed. One such seed was found lying beside the plants.

MOSSES

In addition to the observations that were made of the vascular plants, the distribution of mosses on the island was studied, and samples taken for analysis. In measuring the distribution of mosses the method used was to walk across all the lava and to record the outer boundaries of those areas in which moss was found. In most parts of the lava in the southern section of the island, a special search for moss patches had to be made, as colonies were small and scattered. An aerial photograph was used for fixing their positions from where they were plotted on a map. The distribution of the mosses is shown on the attached map.

Altogether 16 species of mosses were found that could with certainty be classified according to species, as well as species of two genera, which could not be classified further.

TABLE 2

1967	*Funaria hygrometrica* Hedw.	3 samples
	Bryum argenteum Hedw.	1 sample
	Collectors: Bergthór Jóhannsson & Eythór Einarsson.	
1968	*Funaria hygrometrica* Hedw.	9 samples
	Ceratodon purpureus (Hedw.) Brid.	3 samples
	Bryum argenteum Hedw.	1 sample
	Dicranella crispa (Hedw.) Schimp.	1 sample
	Bryum spp.	2 samples
	Pohlia cruda	1 sample
	Collectors: Eythór Einarsson & G. H. Schwabe.	
1969	*Funaria hygrometrica* Hedw.	7 samples
	Bryum argenteum Hedw.	1 sample
	Dicranella crispa (Hedw.) Schimp.	1 sample
	Racomitrium canescens (Hedw.) Brid.	1 sample
	Leptobryum pyriforme (Hedw.) Wils.	1 sample
	Pogonatum urnigerum (Hedw.) Beauv.	1 sample
	Bryum spp.	9 samples
	Collectors: Eythór Einarsson, G. H. Schwabe & Ágúst H. Bjarnason.	

1970	May 9.	May 11.–13.	June 18.–19.	June 26.–27.	July 13.–16.	August 24.–26.	Total
Funaria hygrometrica Hedw.	3	4	9	1	2	7	26
Racomitrium canescens (Hedw.) Brid.	3	5	5		4	5	22
Ceratodon purpureus (Hedw.) Brid.		2	1	3	2	4	12
Leptobryum pyriforme (Hedw.) Wils.					1	4	5
Dicranella crispa (Hedw.) Schimp.			1		1	2	4
Pogonatum urnigerum (Hedw.) Beauv.						2	2
Pohlia wahlenbergii (Web. & Mohr.) Andr.						2	2
Bryum argenteum Hedw.			1				1
Pohlia cruda (Hedw.) Lindb.		1					1
Brachythecium salebrosum (Web. & Mohr.) B. S. G.			1				1
Dichodontium pellucidum (Hedw.) Schimp.					1		1
Drepanocladus uncinatus (Hedw.) Warnst.					1		1
Aongstroemia longipes (Sommer.) B. S. G.						1	1
Atrichum undulatum (Hedw.) Beauv.						1	1
Racomitrium lanuginosum (Hedw.) Brid.						1	1
Bryum pallens Sw.		1	2		1	2	6
Bryum spp.	1	4	7	3	6	7	28
Philonotis sp.		1	1			3	5

Collectors:
- May 9.: Bergthór Jóhannsson.
- May 11.–13.: Hálfdán Björnsson.
- June 18.–19.: Skúli Magnússon & Bjartmar Sveinbjörnsson.
- June 26.–27.: Eythór Einarsson.
- July 13.–16.: Skúli Magnússon & Bjartmar Sveinbjörnsson.
- August 24.–26.: Skúli Magnússon & Bjartmar Sveinbjörnsson.

Bergthór Jóhannsson, of the Icelandic Institute of Natural History, has analyzed all the moss samples from Surtsey, and kept a record of the species and the number of samples every year since the start of the studies. This record is published here, with his permission *(Table 2).* Table 2 shows the names of the species and the number of samples of each species. The Table thus gives some idea of the frequency of each species.

Of the 16 known species of mosses found on Surtsey, 8 are new, found there in 1970, viz:

Racomitrium lanuginosum .	L-12
Atrichum undulatum	Western crater
Aongstroemia longipes	L-12
Drepanocladus uncinatus ..	K-17
Dichodontium pellucidum .	L-12
Brachythecium salebrosum .	L-12
Bryum pallens	L-12, western crater
Pohlia wahlenbergii	L-12, and near the heat emission at the western crater

And in addition *Philonotis* and *Bryum* spp.

If the attached map is compared with the plant map for 1969 (Fridriksson, Bjarnason, Sveinbjörnsson, 1971), the great increase in distribution over the previous year is clearly visible.

Funaria hygrometrica and *Racomitrium canescens,* together with *Bryum* species, are largely responsible for this distribution. Other species have limited distribution in specific places.

Racomitrium canescens grows mainly on bare lava, where there is no sand, but *Funaria hygrometrica* and *Bryum* species grow in caves and beneath protruding lava where sand collects.

Most moss is found near steam emissions, particularly in Surtur I (L-12), where 13 of 16 known species were encountered. *Bryum argenteum* was found at the steam vent in K-10. In a cave in N-9, where there is a steam emission, the following species were found: *Funaria hygrometrcia, Leptobryum pyriforme, Bryum* spp and *Philonotis* sp.

The following species were found on Surtur II (western crater): *Atrichum undulatum, Racomitrium canescens, Pohlia wahlenbergii, Bryum pallens, Funaria hygrometrica* and *Bryum* spp.

Only three species were found with capsules, i.e., *Funaria hygrometrica, Ceratodon purpureus* and *Dicranella crispa.* These species are thus now able to multiply by spores on the island.

DISCUSSION

The vascular plants found on Surtsey during the summer of 1970 had increased in numbers since the previous year from sixty-three to one hundred and one. The four species found, however, were not the same. *Cakile maritima* (Syn: *C. edentula)* did not reappear, but instead four plants of *Stellari media* were discovered. Both *Stellaria media* and *Cochlearia officinalis* seem to be brought in by birds. The seed apparently passes through the alimentary tract of the birds, most likely seagulls, and is deposited with their excrements in the interior of the island.

These spots may become pioneer centers of colonization, and might be succeeded by other higher or lower organisms. Many of these centers are quite naturally formed, but others are influenced by the presence of the containers with rainwater that attract the birds.

These findings collaborate previous observations to the effect that the main dispersal routes to the island of vascular plants are by sea and by birds.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with grant from the U.S. Atomic Energy Commission, Environmental Branch, under the contract No AT (30—1)—3549.

References:

Fridriksson, S., Bjarnason, Á. H. and Sveinbjörnsson, B., 1971: Vascular Plants in Surtsey, 1969.
Surtsey Research Progress Report VI.

Substrate Map of Surtsey 1970

By

STURLA FRIDRIKSSON*, SKÚLI MAGNÚSSON and BJARTMAR SVEINBJÖRNSSON

* The Agricultural Research Institute, Reykjavík, Iceland

INTRODUCTION

In the summer of 1970, S. Magnússon and B. Sveinbjörnsson made a general soil map of Surtsey. Admittedly, it is hardly possible to speak of a real soil, and the map is rather one of the various substrates on the surface of the island. Real soil formation has so far been very small on the island.

The map was made from aerial photograph of the island, which was taken in the autumn of 1970. Drafts of the map were made on the island, but these were corrected during the autumn when the map was being drawn, since there is considerable movement of the sand from one day to the next. An area covered by sand one day may be quite free of sand on the following

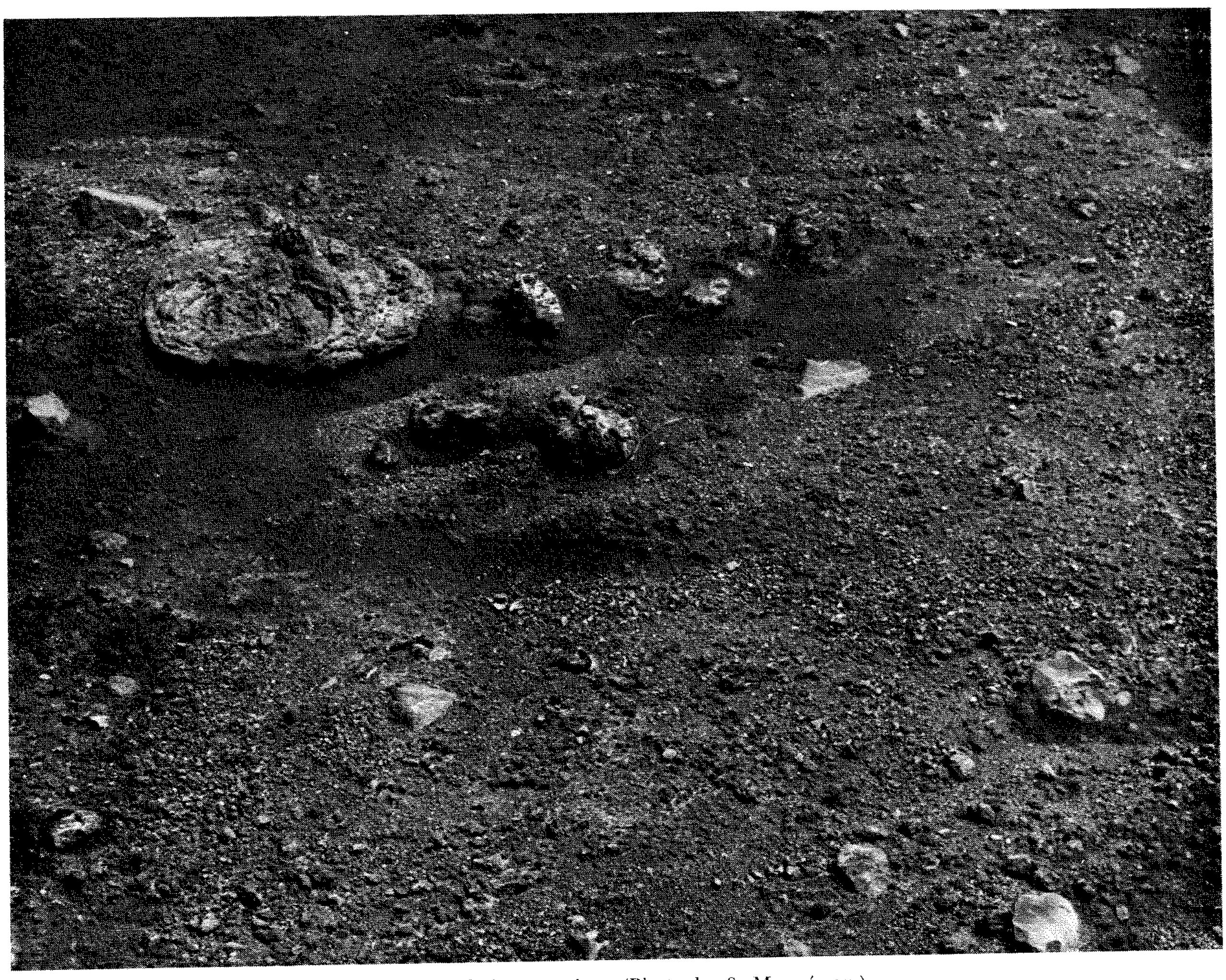


Fig 1. Tephra formed during the first phase of the eruption. (Photo by S. Magnússon.)

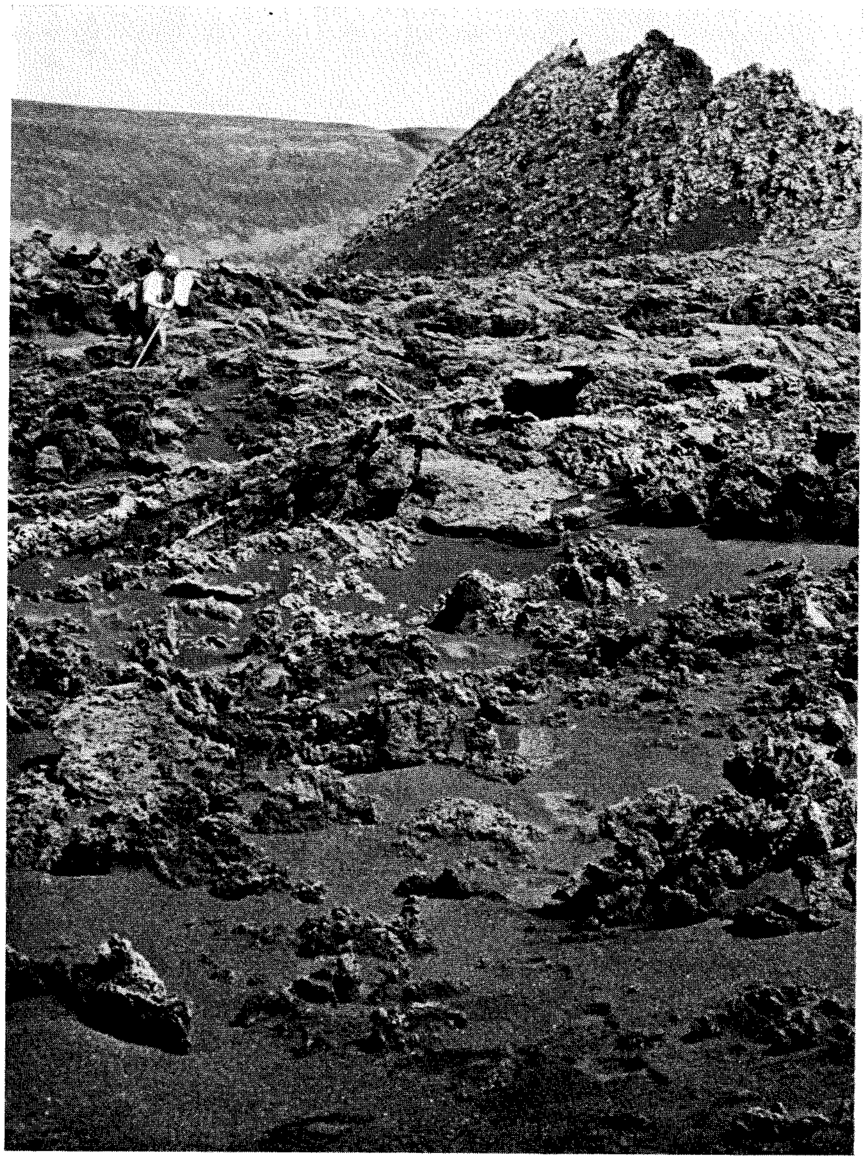


Fig 2. Lava with tephra cover 50—90%. (Photo by S. Magnússon.)

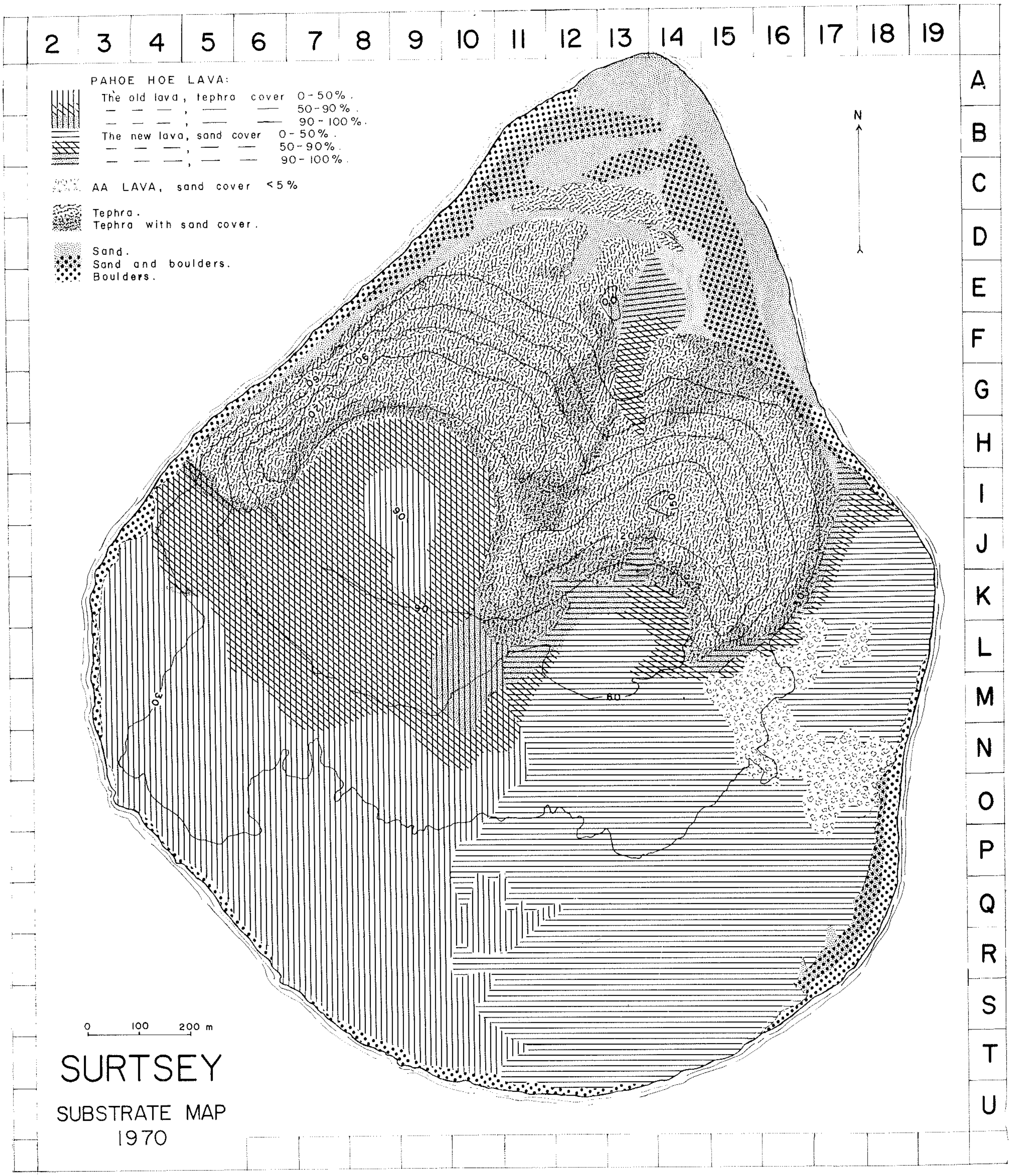
day depending on the weather conditions. There is also a considerable change in the shore line on the northern part of the ness from day to day. During the late summer of 1970, the shore on the eastern part of the ness was covered with large bolders, where it had previously consisted of a smooth sand beach. The change, which took place during a storm one night, shows that the map in question cannot give any complete picture of the distribution of types of substrates on the island, but provides an indication of how it was in the autumn of 1970.

METHOD OF RESEARCH

The following classifications of substrate were employed during the survey and the drawing of the map:

Lava:

1. Old pahoe hoe lava with varying layers of volcanic ash from the Jólnir crater covering 0—50%.
2. Old pahoe hoe lava with varying layers of volcanic ash from the Jólnir crater covering 50—90%.
3. Old pahoe hoe lava with varying layers of volcanic ash from the Jólnir crater covering 90—100%.
4. The new pahoe hoe lava with drift sand covering 0—50%.
5. The new pahoe hoe lava with drift sand covering 50—90%.
6. The new pahoe hoe lava with drift sand covering 90—100%.
7. Aa-lava with sandcover $< 5\%$.


PAHOE HOE LAVA:
The old lava, tephra cover 0-50%.
— — —, — — 50-90%.
— — —, — — 90-100%.
The new lava, sand cover 0-50%.
— — —, — — 50-90%.
— — —, — — 90-100%.
AA LAVA, sand cover <5%
Tephra.
Tephra with sand cover.
Sand.
Sand and boulders.
Boulders.
N
0 100 200 m
SURTSEY
SUBSTRATE MAP
1970
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
A B C D E F G H I J K L M N O P Q R S T U

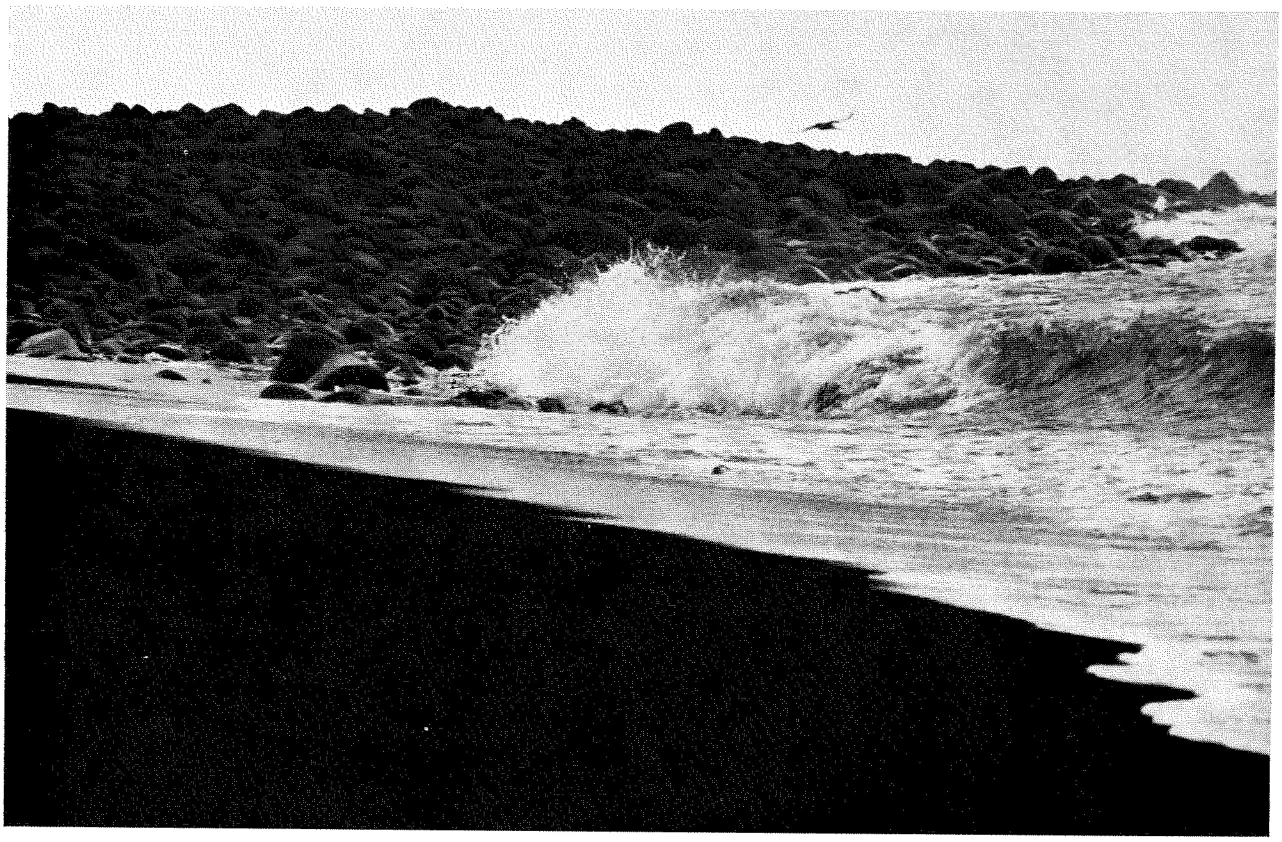


Fig. 3. Sand beach and bolders at the northern point of the ness. (Photo by S. Magnússon.)

Areas with no lava:

8. Tuff.
9. Tuff covered with sand.
10. Sand.
11. Sand and boulders.
12. Boulders (on seashore only).

DISCUSSION

A map of this sort can never be very exact, as it is difficult to follow the contours of each type of terrain accurately. The boundary lines are irregular, and in many cases they depend on the estimate of the individual. Nevertheless, we believe that the map gives a good idea of the approximate situation.

The map was particularly intended for comparison with the plant map of 1970, so that it would be possible to decide in what type of substrate the plants grew.

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with grant from the U.S. Atomic Energy Commission, Enwironmental Branch, under the contract No. AT (30—1)—3549.

Ornithological Work on Surtsey in 1969 and 1970

By
FINNUR GUDMUNDSSON
Museum of Natural History, Reykjavík

1969

In 1969 ornithological work on Surtsey was continued, especially during the spring migration period. Mr. Hálfdan Björnsson and Mr. Völundur Hermódsson stayed on the island from April 11 to May 15 and Mr. Hálfdan Björnsson stayed there again from September 11 to September 18.

All birds seen each day during the above periods were registered and 173 birds were collected. The species and numbers of birds collected in spring were as follows:

Squacco Heron *(Ardeola ralloides)*	1
Grey Lag Goose *(Anser anser)*	2
Barnacle Goose *(Branta leucopsis)*	1
Ringed Plover *(Charadrius hiaticula)*	1
Golden Plover *(Pluvialis apricaria)*	1
Whimbrel *(Numenius phaeopus)*	2
Redshank *(Tringa totanus)*	1
Dunlin *(Calidris alpina)*	1
Short-eared Owl *(Asio flammeus)*	1
Fieldfare *(Turdus pilaris)*	1
Song Thrush *(Turdus philomelos)*	1
Redwing *(Turdus iliacus)*	14
Wheatear *(Oenanthe oenanthe)*	64
European Robin *(Erithacus rubecula)*	1
Meadow Pipit *(Anthus pratensis)*	50
White Wagtail *(Motacilla alba)*	12
Brambling *(Fringilla montifringilla)*	1
Snow Bunting *(Plectrophenax nivalis)*	12
Total	167

In September the following birds were collected:

Ringed Plover *(Charadrius hiaticula)*	1
Wheatear *(Oenanthe oenanthe)*	2
Chiffchaff *(Phylloscopus collybita)*	1
Snow Bunting *(Plectrophenax nivalis)*	2
Total	6

All collected birds were weighed and sexed and their degree of fatness determined according to McCabe's scale proposed in the Auk, 1943. Furthermore, most of the collected birds were prepared as study skins for the Natural History Museum, Reykjavík.

Among the collected birds, the Squacco Heron is new to Iceland while the following species are drift migrants: Field Fare, Song Thrush, European Robin, Brambling, and Chiffchaff. Further drift migrants observed on Surtsey in 1969 but not collected were Sky Lark *(Alauda arvensis)*, Swallow *(Hirundo rustica)*, Jackdaw *(Corvus monedula)*, and Ring Ouzel *(Turdus torquatus)*.

The arrival of Icelandic passerines such as the Wheatear, the Meadow Pipit, and the White Wagtail was somewhat delayed, probably due to unfavourable weather conditions in the British Isles, which may have caused a delayed departure. The peak passage of Meadow Pipits was thus on May 8 although they also passed the island in some numbers on May 2, May 5, and even on May 14. Wheatears passed the island from May 1 to May 15 with peaks on May 8 and May 14 while peak passage of White Wagtails occurred on May 2. As in 1968, there was a very distinct difference between Wheatears and Meadow Pipits as regards degrees af fatness. As in previous years most of the Snow Buntings collected on Surtsey in the spring of 1969 belonged to the nominate race and not to the mostly resident Icelandic race.

Peak passage of the boreal Greylag occurred on April 18 and 19 while the peak passage of the two arctic species, the Pink-footed Goose and the Barnacle Goose, did not take place until the first two days of May and on May 8.

So far no birds have nested on Surtsey, but throughout the summer both Fulmars *(Fulmarus* *glacialis)* and Kittiwakes *(Rissa tridactyla)* have constantly been occupying cliffs on the west side of the island, and Fulmars are probably the most likely birds to become the first nesters there. A pair of Ravens *(Corvus corax)* has also stayed on the island for several years and this pair may sooner or later start nesting there.

1970

In 1970 some ornithological work was carried out on Surtsey as in previous years. Mr. Hálfdan Björnsson stayed on the island from April 18 to May 16. He was accompanied by Mr. Ragnar Jónsson from April 18 to May 12. Throughout the period June 15 to September 11, Mr. Erling Ólafsson and Mr. Björn Jóhannsson were stationed on the island. Both Hálfdan Björnsson and Erling Ólafsson are highly skilled and experienced bird watchers.

All birds seen each day during the above periods were registered and 174 birds were collected. The species and numbers of birds collected were as follows:

Corncrake *(Crex crex)*	1
Oystercatcher *(Haematopus ostralegus)*	1
Ringed Plover *(Charadrius hiaticula)*	2
Golden Plover *(Pluvialis apricaria)*	1
Turnstone *(Arenaria interpres)*	2
Whimbrel *(Numenius phaeopus)*	3
Redshank *(Tringa totanus)*	3
Purple Sandpiper *(Calidris maritima)*	10
Dunlin *(Calidris alpina)*	5
Sanderling *(Crocethia alba)*	4
Red-necked Phalarope *(Phalaropus lobatus)*	25
Puffin *(Fratercula arctica)*	1
Redwing *(Turdus iliacus)*	20
Wheatear *(Oenanthe oenanthe)*	29
Willow Warbler *(Phylloscopus trochilus)*	1
Meadow Pipit *(Anthus pratensis)*	28
White Wagtail *(Motacilla alba)*	15
Brambling *(Fringilla montifringilla)*	1
Snow Bunting *(Plectrophenax nivalis)*	22
Total	174

As in 1969, all collected birds were weighed and sexed and their degree of fatness determined, and most of them were prepared as study skins for the Natural History Museum, Reykjavík.

Among the collected birds the Corncrake *(Crex crex)*, the Willow Warbler *(Phylloscopus trochilus)*, and the Brambling *(Fringilla montifringilla)* are stragglers, which are only known to occur in Iceland during the migration periods. Further drift migrants or stragglers observed on Surtsey in 1970, but not collected, were the Fieldfare *(Turdus pilaris)*, one specimen being seen on May 8, 10, 11, and 12. It may possibly have been the same specimen on all occasions. A male Redstart *(Phoenicurus phoenicurus)* was positively identified on May 14, and a Little Gull *(Larus minutus)* was seen among Great Black-backed Gulls and Kittiwakes on September 3.

The most important ornithological event happening on Surtsey in 1970 was the nesting of the first two species on the island: the Fulmar *(Fulmarus glacialis)*, and the Black Guillemot *(Cepphus grylle)*. One pair of each of the above species nested successfully on the island.

The nest of the Black Guillemot was found on July 27 when it contained two half-grown young. The nest was in a crevice 7 m above sea level in 13 m high cliffs on the south-west side of the island. The young left the nest about August 20. A second nest may possibly have been in the same area but this could not be ascertained satisfactorily. Black Guillemots were common along many parts of the shore of the island, and no doubt will now start to nest there in increasing numbers.

The nest of the Fulmar was found on August 19 on a ledge 10 m above sea level in 25 m high cliffs on the west side of the island. On that day an adult bird was sitting on the ledge beside a not fully grown young. The young left the nest on September 4. That part of the cliffs where the nest was found has been occupied by Fulmars for a number of years. As in the case of the Black Guillemot, the Fulmar is expected to start nesting in this particular area of Surtsey in increasing numbers.

The third species most likely to start nesting on Surtsey is the Kittiwake *(Rissa tridactyla)*. For several years Kittiwakes have been occupying cliffs on the west side of the island some distance away from the cliffs occupied by the Fulmars.

It is intended to publish in one paper the results of the ornithological work carried out on Surtsey in 1969 and 1970.

Nitrogen fixation by blue-green algae on the Island of Surtsey, Iceland

By

ELISABET HENRIKSSON, LARS ERIC HENRIKSSON, and BIRGER PEJLER

Institute of Physiological Botany and Zoological Institute, Uppsala University, Sweden

The colonization of blue-green algae on the new volcanic island Surtsey/Iceland has been studied by Schwabe (1970 a, 1971, Behre & Schwabe 1970). He started his investigation in July 1968, only one year after the violent eruptions which formed the island, had ceased. Already at that time different types of algae were detected, growing in association with each other and with a moss, *Funaria hygrometrica* Hedw.

Among the algae recorded the first summer (1968) only one, *Anabaena variabilis* Kütz., had the potential ability of fixing molecular nitrogen. Next summer (1969), at least three *Nostoc* species with the same ability were detected as well. In these algae the vegetative cells very easily are converted to spores (akinetes). Thus, when conditions are unfavourable for growth, the algae are able to survive for long periods as spores. On Surtsey the spores are very easily transported by wind together with dry ash over wide areas. The original volcanic ash and lava are very unfavourable for growth and nitrogen fixation by blue-green algae on account of the incapability of these substrates to hold water and their high concentration of heavy metals and salt (Schwabe 1970 a, 1970 b, 1971). For that reason experiments have been carried out in order to measure the capacity of the nitrogen fixation in samples collected at different localities on Surtsey, and to find out to which extent nitrogen fixation by blue-green algae occurs in the early phase of the colonization of this island.

The samples studied in this investigation were collected on August 5–9, 1970, at localities where mosses and other lower plants already had developed to a visible layer on the surface of the juvenile soil. For the sake of comparison a few samples from Geysir, in the south-west part of Iceland, have been studied as well.

METHODS AND CULTURAL CONDITIONS

About 1 gram of each sample was put in a small bottle (7 ml volume and 1.4 cm^2 bottom area). 1 ml redistilled water was added to each bottle, and the bottles were fitted with rubber stoppers and kept in a chamber with controlled conditions, 20°C and about 3.000 Lux, during a period of 66 days (Aug. 17 – Oct. 23, 1970). At different times of the period (Aug. 21, Aug. 26, Sept. 16, Oct. 14, Oct. 16 and Oct. 23) the capacity of the nitrogen fixation was measured by using the acetylene-reduction technique (Stewart *et al.* 1967, 1968). Contrary to the original method, the samples in this study were not preserved after the experimental periods. Therefore, the same sample could be used several times. After the analyses had been performed the bottles were aired in 20 minutes to be rid of the unnatural gases, before the incubation continued (Henriksson *et al.* 1972). For practical reasons the period of treatment with acetylene usually exceeded one hour, which may have resulted in the occurrence of unhealthy algal cells, deficient in nitrogen, in our experiments (cf. Stewart 1968).

In order to determine the extent of the heterotrophic nitrogen fixation the reduction of acetylene on Oct. 16 was made in dark and on this occasion the samples had been adapted to dark conditions since the preceding analyses, on Oct. 14.

The determination of the algae involved was made by cultivating small parts of the samples in the following medium, recommended by the IBP project coordinate: A. S. M. Medium (after Gorham *et al.* 1964, modified) K_2HPO_4 17.4 mg, $FeCl_3$ 0.3 mg, E.D.T.A. 7.4 mg, $MgCl_2.6H_2O$ 19.0 mg, $MgSO_4.7H_2O$ 49.0 mg, $CaCl_2.2H_2O$ 14.7 mg, NaCl 58.5 mg, and redistilled water 1.000 ml. Trace elements (after Clendenning *et al.* 1956) $Na_2MoO_4.2H_2O$ 5.0 mg, $CoCl_2.6H_2O$ 0.8 mg, $ZnSO_4.10H_2O$ 0.9 mg, $MnCl_2.4\ H_2O$ 7.2 mg per litre medium.

The identification of the nitrogen fixing algae was made according to Geitler (1932).

RESULTS AND DISCUSSION

The results concerning nitrogen fixation in juvenile soils of Surtsey are shown in Table 1. According to the results received, algae are in fact fixing molecular nitrogen at this early phase of colonization. However, in five of the localities studied (S 21, 22, 23, 24, 20) the capacity of the nitrogen fixation seems to be very low, and in the other localities (S 7, 27, 18, 8, 14) the nitrogen fixation is rather low compared to that occurring at Geysir. If the eventual enfeeblement of the algal cells which may be caused by the long treatment with acetylene, is left out of account (see Methods and Cultural Conditions), the conditions involved in our experiments may on the whole be better than those usually occurring on Surtsey. Therefore, it may be concluded that the nitrogen fixation of the algal pioneers probably occurs at a rather low level. In spite of this, the nitrogen fixed may be of great importance for the following immigration of plants and animals.

The table also shows that nitrogen fixation occurs in dark, possibly caused by bacteria. However, there are also possibilities that the algae, in spite of being kept in dark during such a long time as two days before the acetylene treatment was made (see Methods and Cultural Conditions), still had the ability of fixing nitrogen in dark on account of their utilization of stored photosynthetic products.

The extent of the algal nitrogen fixation occurring in soils in other parts of the northern temperate zone is surveyed and discussed by Henriksson (1971).

Table 2 shows the algae involved in the analyses and a short description of the localities studied. It is evident that only the presence of potential nitrogen fixing algae in a sample cannot give the whole picture concerning the extent of nitrogen fixation, since the qualifications of the substrate is of decisive importance.

ABSTRACT

Blue-green algae occurring as pioneers on Surtsey/Iceland, are shown to fix nitrogen in the juvenile soil of volcanic origin of this island.

ACKNOWLEDGEMENT

This work is part of an IBP-project on the distribution and ecological importance of nitrogen-fixing blue-green algae and was supported by the Swedish Natural Research Council.

Table 1.

Values of the analyses on the capacity of the acetylene-reduction in different soil samples, collected on Surtsey (S) and at Geysir (G). The extent of the nitrogen fixation is calculated by using the theoretical 3:1 ratio for C_2H_2 reduced: N_2 fixed.

Only the highest value received during the incubation time in light is here presented (see Methods and Cultural Conditions). The figures in parenthesis mean the number of parallels. Each sample weighed about 1 gram and had an area of about 1.4 cm^2.

Table 1.

Sample	nmoles C_2H_4/sample/hr		ng N_2 fixed/sample/hr	
	In light	In dark	In light	In dark
S 21	0.2 (1)	0 (1)	2	0
S 22	0.2 (1)	0 (1)	2	0
S 24	0.2 (1)	0 (1)	2	0
S 20	0.4 ± 0.0 (4)	0 (4)	4	0
S 7	0.9 ± 0.6 (2)	0.4 ± 0.2 (2)	8	4
S 27	1.0 ± 0.0 (4)	0.4 ± 0.0 (4)	9	4
S 18	3.2 ± 0.9 (2)	0.4 ± 0.1 (2)	30	4
S 8	3.5 ± 0.4 (2)	0.3 ± 0.1 (2)	33	3
S 14	5.8 ± 1.0 (5)	1.0 ± 0.6 (4)	54	9
G 2	14.3 ± 9.0 (3)	0.5 ± 0.2 (2)	133	4
G 1	16.3 ± 5.7 (2)	3.2 (1)	152	30
G 3	57.9 ± 7.0 (4)	6.0 ± 2.2 (4)	540	56

Table 2.

Short description of the localities studied on Surtsey (S) and at Geysir (G). The localities S 14 and S 18 on Surtsey are situated in the lava fields, all other Surtsey localities in the ashy areas in connection with steam vents where condensation of water occurs (cf. Schwabe 1970 b). The potential nitrogen fixing algae (cf. Stewart 1966) cultivated from each sample are also recorded. They were identified according to Geitler (1932).

Table 2.

Sample	Description of the locations	Occurrence of potential nitrogen fixing algae
S 21	Sparsely moss-covered, rather moist, solid substrate.	—
S 22	Visible blue-green algae. Moist, solid substrate.	*Nostoc muscorum* Ag.
S 24	Densely moss-covered, moist, solid substrate.	*N. muscorum*
S 20	Densely moss-covered, very moist, solid substrate.	—
S 7	Densely moss-covered, moist, solid substrate.	*N. muscorum*
S 27	Densely moss-covered, moist, solid substrate.	*Anabaena variabilis* Kütz., *N. muscorum*
S 18	Densely moss-covered substrate. Shadowy.	*A. variabilis*
S 8	Dried puddle. Superficial soil layer down to a depth of about 2 mm.	*A. variabilis*
S 14	Densely moss-covered substrate. Near the shore. Birds were common.	*Nodularia Harveyana* Thur., *N. muscorum*, *Tolypothrix* sp.
G 2	Visible blue-green algae. Moist soil.	*A. variabilis*
G 1	Visible blue-green algae. Moist soil.	*A. variabilis*
G 3	Visible blue-green algae. Moist soil.	*A. variabilis*

References:

Behre, K. & Schwabe, G. H., 1970: Auf Surtsey/Island im Sommer 1968 nachgewiesene nicht marine Algen. — Schr. Naturw. Ver. Schlesw-Holst. Sonderband: 31—100.

Clendenning, K. A., Brown, T. E. & Eyster, H. C., 1956: Comparative studies of photosynthesis in *Nostoc muscorum* and *Chlorella pyrenoidosa*. — Canad. J. Bot. 34:943-966.

Geitler, L., 1932: Cyanophyceae von Europa unter Berücksichtigung der anderen Kontinente. — Rabenhorsts Kryptogamenflora 14.

Gorham, P. R., MacLachlan, R., Hammer, U., & Kim, W. D., 1964: Isolation and culture of toxic strains of *Anabaena flos-aquae* (Lyngb.) de Bréb. — Verh. int. Ver. Limnol. 15:796—803.

Henriksson, E., 1971: Algal nitrogen fixation in temperate regions. — Plant and Soil, Special Volume. In press.

Henriksson, L. E., Enckell, P. H., & Henriksson, E., 1972: Determinations of nitrogen fixing capacity of algae in different soils. — Oikos 23.

Schwabe, G. H., 1970 a: Blaualgen und Vorstufen der Bodenbildung auf vulkanischem Substrat (bisherige Befunde auf Surtsey/Island). — Mitt. Dtsch. Bodenkundl. Ges. 10:198-199.

—— 1970 b: Zur Ökogenese auf Surtsey. — Schr. Naturw. Ver. Schlesw.-Holst. Sonderband: 101—120.

—— 1971: Blue-green algae as pioneers on postvolcanic substrate (Surtsey/Iceland). — Proc. 1st Int. Symp. Taxonomy and Biology of blue-green algae. Madras 1970. In press.

Stewart, W. D. P., 1966: Nitrogen fixation in Plants. — The Athlone Press, London.

—— 1968: Nitrogen input into aquatic ecosystems. — In: Algae; Man, and the Environment. Ed. D. F. Jackson. Syracuse, New York.

Stewart, W. D. P., Fitzgerald, G. P., & Burris, R. H., 1967: *In situ* studies on N_2 fixation using the acetylene reduction technique. — Proc. nat. Acad. Sci. Wash. 58:2071—2078.

—— 1968: Acetylene-reduction by nitrogen-fixing blue-green algae. — Arch. Microbiol. 62:336—348.

On the Terrestrial Microfauna of Surtsey During the Summer 1970

By

OLOF HOLMBERG and BIRGER PEJLER

Zoological Institute, University, Uppsala, Sweden

INTRODUCTION

In August 1970 B. Pejler accompanied Prof. C. H. Lindroth on his expedition to Surtsey. On the way to the island Dr. G. H. Schwabe joined us and showed us the localities of the first known plant settlements above the highest water-line, found by him in previous years and described in earlier communications (see Behre and Schwabe 1970, with references). Some samples were collected from these patches of algal and moss vegetation for investigation of the microfauna.

DESCRIPTION OF THE LOCALITIES

Only the localities where microzoa were encountered are mentioned here. On all observation occasions the cultures from several localities were found to contain only algae, while others showed no organisms at all.

In most cases the animals reported were observed in all the cultures from the localities where they were found. In cases where our locality is the same as one of Schwabe's, the number used by him is mentioned within brackets after our designation.

The localities S 14 and S 18 are situated in the lava area, below the highest water-line, S 22 in the lowest part of the passage between the tephra cones of Surtur I and Surtur II, straight W of the "New Year Crater". All other localities are situated in the crater area of Surtur II, on tephra ground, close to steam exhalations.

Some details concerning the localities:

S 7 (315)	1 m S of the fenced (preserved) area. Dense growth of mosses.
S 8 (307-308)	Surface layer (2 mm) of a dried-up pool.
S 14 (319)	Just above the water-line (and at times flushed by the waves). With sporulating moss. Possibly manured by birds.
S 18 (329)	Lava cave, ca. 200 m E of Klofi, about 30 m above sealevel. Moss-covered area at least 100 cm^2.
S 20 (333)	"The Bell", a crater forming a bell-shaped cave, into which the light penetrates only from one direction, although the insolation is rather weak because of a "misty curtain" of condensed steam. The illuminated wall was densely covered by moss (the most intense and extended vegetation observed anywhere on Surtsey this year). The internal walls were dripping with water and had a temperature of $+20°- +40°C$.
S 21 (334 a)	Moss patch ca. 10 m below "The Bell", on a rather steep slope. The tephra substrate was rather firm, moist and somewhat heated.
S 22	"Scatella-locality", so-called owing to the finds of imagines of *Scatella tenuicosta* Coll. (Ephydridae, Diptera, det. Hugo Andersson). The tephra substrate relatively firm, soaked with condensed water and with a discernible layer of blue-green algae.
S 27	Moss patches immediately E of the fenced area (cf. S 7).

METHODS

The samples were taken to the Institute of Plant Physiology in Uppsala under sterile conditions, where they were inoculated (one week after the collection) to either firm substrates (agar), or a liquid nutrient solution (8 cultures from each sample). The last-named cultures were also used to determine the nitrogen fixation. The composition of the medium is given in Henriksson, Henriksson & Pejler 1971. The cultures were kept in a chamber with controlled conditions, +20°C and about 3000 Lux and with a humidity balanced in order to avoid exsiccation. Renewed inoculation (in order to get a "fresh" substrate) was made on Nov. 20, 1970 and on April 5, 1971. Microscopic examination was made at intervals from August 1970 to May 1971.

All measures were taken in order to avoid contamination of the samples and the cultures. Most species were found in several cultures, and in such cases, at least, their occurrence on Surtsey ought to be considered as certain. In some cases, however, only single observations were made, which is designated in the table with an asterisk. However, also in these cases the risk of contamination is considered as being small (cf. Behre and Schwabe, op. cit., pp. 41 and 65).

COMMENTS ON THE TAXONOMY

The taxonomy of the nude amoebae is far from definite, different authors having different ideas concerning the separation of species and genera, owing to the extremely high individual variability, for example. The characters exhibited depend to a high degree on the environmental conditions, and it is thus often impossible to compare the material with the results of authors using other culture methods or making direct observations (moreover, the environmental conditions are often not mentioned in the literature). Therefore, in several cases it is meaningless to mention the names of the species, even if the forms are in complete agreement with descriptions found in the literature. In such cases species names are omitted. The determinations are based on lengthy observations on several individuals in order to get a picture, as complete as possible, of the different phases. Concerning the rhizopods we mainly follow the exposition by Harnisch (1960), from which we sometimes deviate, however, when it is necessary to get the taxonomy more up to date.

Concerning the designation of the *Habrotrocha* form, Donner will give more detailed comments in a future paper on Bdelloidea.

COMPOSITION OF THE FAUNA IN 1970

The observations made in the different cultures are presented in Table 1. The nematode reported by Sohlenius (1972) was also encountered in cultures reared from samples collected in 1971 by G. H. Schwabe. As far as can be judged from the literature, the forms observed are widespread, often cosmopolitic, and capable of enduring severe environmental conditions. Some of them, for example, are reported from the Antarctic (Dillon, Walsh and Bierle 1968, Donner 1965). Studies of the literature suggest that all animals observed are able to reproduce asexually or parthenogenetically, at least temporarily. In most species the whole animal can be rapidly transformed into a resting stage capable of exsiccation, freezing and distant dispersal (see, e.g., Kahl 1930, Grospietsch 1965, Donner, op. cit., Sohlenius, op. cit.).

CHOICE OF FOOD

Table 2 shows the observations of food intake, as well as corresponding data found in literature. Of course this exposition implies that other types of food can also be utilized. Thus, it is highly probable that bacteria also play an important role for the amoebae concerned. It is true that no such ingestion was observed, but bacteria-like structures were often found in their interiors.

Regarding the grazing effect, the material does not, of course, permit any conclusion, but it should be pointed out how voracious some of the amoebae were found to be, *Thecamoeba* sp., for example, being usually stuffed with blue-green algae.

As far as the amoebae are concerned it was quite obvious that moving objects were not ingested. All animals observed, as far as can be judged, are herbivorous. In other words, the ecological pyramids of the small eccosystems concerned should be formed by only two trophic levels.

APPENDIX: SOME FINDS FROM FRESHWATER ENVIRONMENTS

Samples were collected from traps (plastic tanks) originally set out by B. Maguire. In addition to some of the forms already reported by this author (Maguire 1970) the species mentioned in Table 3 were also detected. They were observed by direct microscopic examination. The nematodes discussed by Sohlenius (op. cit.) were also found in trap No. 4.

ABSTRACT

Samples of moss and algal vegetation from the island of Surtsey/Iceland were cultured on both solid and liquid substrates. About ten different microzoa were found, belonging to Rhizopoda, Ciliata, Rotatoria and Nematoda. They are all

characterized by great resistance to environmental extremes, wide distribution and a way of propagation (asexual etc.) which enables distant dispersal. Only vegetable matter (algae, bacteria) was observed to be eaten by all these forms.

ACKNOWLEDGEMENTS

We express our sincere gratitude for advice and pleasant collaboration, especially to Porf. C. H. Lindroth, Lund, Dr. G. H. Schwabe, Plön, and Drs. Elisabet and L. E. Henriksson, Uppsala. The ciliate mentioned was determined by Dr. Anna Czapik, Kraków, the bdelloid rotifers by Dr. J. Donner, Katzelsdorf (Austria). The field work was sponsored by the Swedish National Science Research Council and by the Surtsey Research Society.

TABLE 1

Occurrence of the forms in the different localities during 1970

Locality	S 7	S 8	S 14	S 18	S 20	S 21	S 22	S 24	S 27
RHIZOPODA, AMOEBINA									
Vahlkampfia, limax-type	×	..	..	..	..	×	..	×	..
Vahlkampfia, guttula-type*	..	..	×	..	..	..	..	..	..
Naegleria soli Mart. and Lewin	×	×	..	..	..	..	..	..	×
Naegleria bistadialis Puschkarew	×	..	..	×	..	..	..	..	×
Trichamoeba sp.*	..	..	..	..	..	..	..	×	..
Mayorella vespertilio Penard*	..	..	..	..	..	..	..	..	×
Dactylosphaerium sp.	..	×	..	×	..	..	..	..	..
Vexillifera ambulacralis Penard*	..	..	..	..	..	..	..	×	..
Astramoeba stella Schaeffer	..	×	..	×	×	..	..	..	..
Astramoeba sp.	..	..	..	..	..	..	×	..	..
Thecamoeba striata Penard*	..	..	..	..	..	..	..	..	×
Thecamoeba sp.	..	..	×	..	..	..	×	×	..
Nuclearia sp.*	..	×	..	..	..	..	..	..	..
RHIZOPODA, TESTACEA									
Euglypha sp.	×	..	..	..	..	..	..	..	..
CILIATA									
Cyclidium citrullus Cohn	..	..	..	..	..	..	×	×	..
undetermined forms	×	×	×	..	×	×	..	..	×
ROTATORIA, BDELLOIDEA									
Philodina acuticornis odiosa Milne	..	..	×	..	×	×	..	..	..
Habrotrocha constricta Dujardin — *elusa vegeta* Milne-group	..	..	×	..	..	..	..	..	..

TABLE 2

Food sources of the forms observed

	according to own observations	according to literature
RHIZOPODA, AMOEBINA		
Vahlkampfia, limax-type	*Chlamydomonas*	
Vahlkampfia, guttula-type	*Nostoc*	
Naegleria soli	*Nostoc*	
Naegleria bistadialis		
Trichamoeba sp.		
Mayorella vespertilio	*Chlamydomonas, Nostoc*	diatoms, green algae (Mackinnon & Hawes 1961)
Dactylosphaerium sp.	blue-green algae	
Vexillifera ambulacralis		} flagellates (Penard 1902)
Astramoeba stella		} flagellates (Penard 1902)
Astramoeba sp.		} flagellates (Penard 1902)
Thecamoeba striata	*Nostoc*	} flagellates (Penard 1902)
Thecamoeba sp.	blue-green algae	
Nuclearia sp.		
RHIZOPODA, TESTACEA		
Euglypha sp.		diverse algae (Grospietsch 1965)
CILIATA		
Cyclidium citrullus		bacteria (Kahl 1931)
ROTATORIA, BDELLOIDEA		
Philodina acuticornis		diatoms (Donner 1965)
Habrotrocha sp.		detritus (Lucks 1929)
NEMATODA		
Acrobeloides nanus		bacteria (Sohlenius 1972)

TABLE 3
Microfauna observed in Maguire's traps

	Trap number 1	2	3
RHIZOPODA, HELIOZOA			
Actinophrys sol Ehrbg	×	..	..
ROTATORIA, MONOGONONTA			
Euchlanis dilatata Ehrbg	..	×	..
Cephalodella gibba (Ehrbg)	×	..	..
Cephalodella gracilis (Ehrbg)	..	..	×

References:

Behre, K. and Schwabe, G. H. 1970: Auf Surtsey/Island im Sommer 1968 nachgewiesene nicht marine Algen. Schr. Naturw. Ver. Schlesw.-Holst., Sonderband, pp. 31—100.

Dillon, R. M., Walsh, G. L. and Bierle, D. A. 1968: A preliminary survey of Antarctic meltwater and soil Amoeba. Trans. Amer. Microsc. Soc. 87, pp. 486—492.

Donner, J. 1965: Ordnung Bdelloidea. *In:* Bestimmungsbücher zur Bodenfauna Europas, Lief. 6. Berlin. 297 pp.

Grospietsch, Th. 1965: Wechseltierchen (Rhizopoden). *In:* Einführung in die Kleinlebewelt. Stuttgart. 84 pp.

Harnisch, O. 1960: Rhizopoda. *In:* Die Tierwelt Mitteleuropas, Bd 1, Lief. 1 b. Leipzig. 75 pp.

Henriksson, E., Henriksson, L. E. and Pejler, B. 1971: Nitrogen fixation by blue-green algae on the island of Surtsey/Iceland. Surtsey Res. Progr. Rep. 6.

Kahl, A. 1930: Urtiere oder Protozoa I: Wimpertiere oder Ciliata 1, pp. 1—180. *In:* Die Tierwelt Deutschlands, Teil 18. Jena.

Kahl, A. 1931: Urtiere oder ... Ciliata 3, pp. 399—650. Ibid., Teil 25.

Lucks, R. 1929: Rotatoria. *In:* Biologie der Tiere Deutschlands, Lief. 28, Teil 10. Berlin. 176 pp.

Mackinnon, D. L. and Hawes, R. S. J. 1961: An introduction to the study of Protozoa. Oxford. 506 pp.

Maguire, B. Jr. 1970: Surtsey's freshwater biota after 14 months. Surtsey Res. Progr. Rep. 5, pp. 60—62.

Penard, E. 1902: Faune Rhizopodique du Bassin du Léman. Genève. 714 pp.

Sohlenius, B. 1972: Nematodes from Surtsey. Surtsey Res. Progr. Rep. 6.

Mycological Investigations – VI

By
T. W. JOHNSON, Jr.
Department of Botany, Duke University,
Durham, North Carolina 27706.

In a previous report (Johnson, 1970), I emphasized what appears to be a significant aspect of the Icelandic aquatic mycoflora, namely, the abundance of forms or variants that are useful in studying the ranges of species variation. The bulk of the work during 1969 and 1970 on the aquatic fungi of Iceland involved many of these variants in attempts to discover limits to species diversity in particular groups of aquatic fungi. In the report to follow, certain of these studies are summarized.

Representatives of eight genera of the Saprolegniaceae are now known to occur in Iceland (Howard *et al.*, 1970). Four species of *Aphanomyces* have been identified, but these probably do not represent the total number of taxa in the genus in Iceland. Currently, I am intensifying the field work in attempts to study this genus further. Snakeskin, roach wings, and boiled cellophane have been the baits of choice in collecting species of *Aphanomyces* from water and soil samples. *Pythiopsis cymosa* is common on fish in the hatcheries near Reykjavík, but the usual habitat for the fungus is soil and water.

A number of taxonomic changes in the Saprolegniaceae have been made as a result of the study of specimens from Iceland. Chief among the changes has been the recognition of *Saprolegnia torulosa* as the valid name embracing such long-standing species as *S. monilifera, Isoachlya monilifera,* and *Isoachlya torulosa*.

Eight species of *Olpidium* (Chytridiales) and seven species of *Phlyctochytrium* (Chytridiales) have been found in Iceland (Johnson, 1969a, b). Variants or forms of several species have been described, and distributional records extended. For example, *Phlyctochytrium indicum* Karling has been collected on Heimaey; its only other record is the original collection from New Zealand. Also found on Heimaey is Sparrow's *Olpidium rhizophlyctidis*, a parasite of a fungus in the genus *Rhizophydium*. The other known sites for this species are the Marshall Islands and Cuba.

During 1969 and 1970, I gave particular attention to a study of three species of Chytridiales with gibbose sporangia. The morphological variation in generous collections of *Chytridium schenkii* led me to conclude that Scherffel's *C. gibbosum* is a synonymous species.

Within the biflagellate aquatic fungi, I have found substantial material of species of *Olpidiopsis* and *Pythium*. Members of *Olpidiopsis* are parasitic on other fungi and in algae. While I have been unable to culture these fungi (and thus study their morphology extensively), there is substantiating evidence for taxonomic changes to be made. One species (evidently new to science) of *Olpidiopsis* occurs in *Chara*(?) in Iceland.

Much of the mycological effort in 1969 and 1970 went into characterization and taxonomy of isolates of *Pythium* from Iceland's soils and waters (and from filamentous green algae). Members of this genus are free-living in soil and water, or are parasitic on other plants. These fungi are very common in Iceland, but many of the specimens collected did not reproduce sexually even in pure culture. In my study of the isolates at hand, I have attempted to characterize species in such a way as to indicate something about their ranges of variation.

These species of *Pythium* have been discovered in Iceland: *P. debaryanum, P. dissotocum, P. echinulatum, P. gracile, P. inflatum, P. mamillatum, P. middletonii, P. monospermum, P. pulchrum, P. rostratum, P. tenue, P. torulosum, P. ultimum, P. undulatum* and *P. vexans*. The Iceland specimens, *in toto,* would be important in any future monograph of the genus since they generally seem to be highly variable, and in a genus as complex as *Pythium,* it is essential to know as much of morphological variability as is possible if meaningful taxonomic judgments are to be made.

In the genus *Pythium,* as in other genera of aquatic fungi studied in Iceland, there are substantial new records of occurrence. *Pythium dissotocum,* for example, inhabits roots of vascular plants, but in Iceland it occurs in soil. Before its discovery in the Laugarvatn area, *P. inflatum* was known only from North Carolina. Other species — such as *P. debaryanum* and *P. ultimum* — are very widely distributed, being found both in Europe and in North America, and it is not surprising to recover them also in Iceland.

There are numerous species complexes yet to be studied. Outstanding among these is the galaxy of forms revolving about the species of *Chytridium* and *Rhizophydium* with globose sporangia. These fungi are very common in Iceland in the soils below tufts of grasses and *Rhacomitrium.* In addition to projected studies on these aquatic fungi, there is a need for an intensive investigation of aquatic species developing on submerged twigs and rosaceous fruits. This portion of the aquatic mycoflora of Iceland has been touched upon in only the most superficial of ways. I have collected some species of the filamentous, biflagellate groups on submerged apples and birch twigs, but these have generally been members of *Pythium* and of the Saprolegniaceae. It is surprising that members of *Blastocladia, Rhipidium, Sapromyces,* and *Monoblepharis* have not occurred on twigs or fruits submerged in various streams in southwestern Iceland.

A very substantial contribution to our knowledge of the mycoflora of Iceland has been made by E. V. Laube, Jr., Duke University (doctoral dissertation) on the mucoraceous fungi and coprophilus Ascomycetes. Fifty-two species of mucoraceous fungi, representing eleven genera in seven families have been isolated from soils and dung from Iceland. As has been the case with the aquatic fungi, there is an abundance of variants and forms of mucors among the specimens isolated. Accordingly, certain txonomic changes hve been made in several genera, based on the results of camparative morphological studies: *Mortierella, Rhizopus, Spinalia,* and *Mucor.* New taxa are described in the genera *Absidia, Mortierella, Zygorhyncus, Spinalia,* and *Thamnidium.*

Laube (dissertation, 1971) also reports forty-seven species of ascomycetes from soil and dung. These species (some of which are as yet not named or positively identified) represent twenty-two genera.

ACKNOWLEDGEMENT

The research support provided by the National Science Foundation through Grant GB-6393 is acknowledged with gratitude. The laboratory and field work would not be possible without the advice and encouragement given so generously by Dr. Eythór Einarsson and Steingrímur Hermannsson. I am grateful for continued use of laboratory space in the Museum of Natural History.

References:

Howard, K. L., R. Seymour, and T. W. Johnson, Jr. 1970. Aquatic fungi of Iceland: Saprolegniaceae. Jour. Elisha Mitchell Sci. Soc. 86: 63—79.

Johnson, T. W., Jr. 1969a. Aquatic fungi of Iceland: *Phlyctochytrium* Schroeter. Arch. Mikrobiol. 64: 357—368.

—. 1969b. Aquatic fungi of Iceland: *Olpidium* (Braun) Rabenhorst. Arch. Mikrobiol. 69: 1—11.

—. 1970. Mycological investigations — V. Surtsey Progress Report V, 1970.

Marine Benthic Algae Recorded in Surtsey During the Field Seasons of 1969 and 1970

By

SIGURDUR JÓNSSON

Surtsey Biological Laboratory, Vestmannaeyjar and

Laboratoire de Biologie Végétale Marine, Université de Paris

Investigations on the marine algal colonization of Surtsey were conducted in 1969 and 1970 in the same way as the year before (1). Sampling, carried out during the summer season (july—august), was again centered on the rocky shore bordering the lava cliffs as well as offshore in the sublittoral zone, down to the lower limit of macroscopic algae, situated at about 20 m depth. Underwater collections were made by SCUBA diving.

COMPOSITION OF THE MARINE ALGAL FLORA

An analysis of the material collected led to the identification of species listed below. Diatoms species are excluded. The nomenclature adopted is that proposed by Parke and Dixon (2).

It appears that 24 algal species were found growing around Surtsey in 1969 and 25 species in 1970. To this must be added many species of benthic Diatoms, the most common of which was *Navicula ramosissima,* already settled at Surtsey.

ON THE MARINE ALGAL SETTLEMENT

Among the species identified during the present survey only a few are new invaders in the marine environment of Surtsey.

In the littoral zone the only new elements were marine myxophyceae, found in 1970, in high lying rock pools on the NE coast. The remaining species identified in the littoral zone had already colonized the island (1). These species appear thus to be a rather constant elements of the littoral flora — at least in its present stage of development.

Species	Littoral 1969	Littoral 1970	Sublittoral 1969	Sublittoral 1970
MYXOPHYCEAE:	..	×	..	..
CHLORPHYCEAE:				
Ulothrix flacca	×	×	..	..
— *pseudoflacca*	×	×	..	..
— *consociata*	×	×	..	..
Urospora pencilliformis	×	×	..	..
— *wormskioldii*	..	..	×	..
Codiolum gregarium	×	×	..	..
Acrosiphonia albescens	×	..	..	..
Enteromorpha prolifera	×	×	..	..
— *compressa*	×	×	..	..
Ulva lactuca	..	..	..	×
PHEOPHYCEAE:				
Ectocarpus confervoides	×	×	×	×
Giffordia hincksiae	..	..	×	×
— *granulosa*	..	..	×	..
Petalonia fascia	×	×	..	..
— *zosterifolia*	×	×	..	..
Scytosiphon lomentarius	..	..	×	..
Desmarestia viridis	..	..	×	×
— *ligulata*	..	..	×	×
Laminaria hyperborea	..	..	×	×
— *digitata*	..	..	..	×
Alaria esculenta	..	..	×	×
RHODOPHYCEAE:				
Porphyra umbilicalis	×	×	..	..
— *miniata*	..	..	×	×
Euthora cristata	..	..	..	×
Lomentaria orcadensis	..	..	..	×
Antithamnion floccosum	..	..	×	×
Phycodrys rubens	..	..	×	×
Polysiphonia urceolata	..	..	×	×
Total number of species	12	12	13	14

×=present

In the sublittoral zone the settlement was progressing somewhat faster as 4 new colonizing species were encountered, namely: *Ulva lactuca, Euthora cristata, Laminaria digitata* and *Giffordia granulosa,* the last mentioned being a new record for Iceland. Some species, such as *Desmarestia aculeata* and *Monostroma grevillei,* already settled in 1968, were not found again. Some variations in the composition of the deep water flora could also be noted. Species, such as *Urospora wormskioldii, Scytosiphon lomentarius* and the newly recorded *Giffordia granulosa,* present in 1969, were not rediscovered in 1970.

The new colonizers were represented by isolated individuals. They did not affect the general aspect of the marine algal vegetation. As previously (1,3) two major belts formed the littoral zone, an upper one of *Urospora penicilliformis,* and a lower one of *Navicula ramosissima,* locally strewn with pure stands of *Petalonia fascia* and *Petalonia zosterifolia. Enteromorpha prolifera* populations were found to be spreading out in selected places, mainly on exposed vertical rocks. The sublittoral growth was, as previously, essentially dominated by *Alaria esculenta* populations.

It was formerly pointed out (3) that the marine benthic algal colonization is a long term process in Surtsey's water and the algal vegetation is far from having reached the stage of development observed in neighbouring floral areas. The main obstacle actually met with by the settlers is obviously the instability of the substrate. The marine erosion is as yet quite intensive everywhere along the heavy exposed coast of the island (4). Thus, the basalt cliffs are known to have locally retreated by about 100 m in one year. It is evident that the settlement and the development of the marine benthic populations are particularly difficult under such conditions.

References:

(1) Jónsson, S. 1970: Studies of the colonization of marine benthic algae at Surtsey in 1968. Surtsey Res. Progr. Report V, p. 42—51.

(2) Parke, M. and Dixon, P. 1968. Check-list of British marine algae. J. mar. Biol. Ass., U.K., *48,* 783—832

(3) Jónsson, S. 1970. Meeresalgen als Ertsbesiedler der Vulkaninsel Surtsey. Schr. Naturw. Ver. Schlesw.-Holst., Sonderband, 21—28.

(4) Moign, Y. et Moign, A. 1970. Les îles Heimaey et Surtsey de l'archipel volcanique Vestmannaeyjar (Islande). Etude du littoral. Norois, 67, 305—334.

Studies on Lichen Colonization in Surtsey 1970

By

HÖRDUR KRISTINSSON

Surtsey was visited in the summer of 1970 for study of lichen colonization. Samples were collected in different habitats, much in the same way as in 1968 (Kristinsson 1970). Communities of lichens were detected around the crater Surtur II. Three species, *Trapelia coarctata* (Sm. & Sow.) Choisy, *Placopsis gelida* (L.) Lind. and *Stereocaulon vesuvianum* Pers. were identified in the samples brought back from this excursion. These were the first lichens ever found on the island. A second trip had been planned later in the summer to provide some more information on the distribution and the structure of this community, but had to be delayed until 1971.

HABITATS

The lichens were found in two different places in the vicinity of Surtur II. Both habitats were influenced by warm steam. One of them was a level lava block northeast of the crater, periodically kept moist by steam coming out of a crack. At this place only tiny pieces (single phyllocladia) of a *Stereocaulon* were detected by a lens. A depressed, dark spot in the center of the phyllocladia indicates that they belong to *Stereocaulon vesuvianum,* which is one of the major pioneer lichen species rapidly colonizing all new lava fields throughout Iceland.

The second habitat was much richer in lichen vegetation, a north-facing steep slope of lava rock on the outside of the crater Surtur II. Here a community with an extension of several meters was formed by only two lichen species and kept damp by warm steam. One of them, *Trapelia coarctata* was present in such quantities, as to turn the rocks pale yellowish brown, not always easily recognizable against the almost concolored mineral residues found here and there on the rocks around the crater. *T. coarctata* is a crustose lichen, already found with a great number of spore-producing apothecia in Surtsey. It appeared to be closely associated with water tracks on the rock surface, as if it were distributed mainly by rainwater from the top to the base of the crater.

The other species, *Placopsis gelida,* was found here and there growing together with *T. coarctata.* The specimens were rather small and not fertile, but some were sorediate.

DISTRIBUTION IN ICELAND

Two of the lichen species here recorded for Surtsey, *Stereocaulon vesuvianum* and *Placopsis gelida,* are very common throughout Iceland.*S. vesuvianum* is especially abundant in postglacial lava fields, frequently associated with *Rhacomitrium lanuginosum. P. gelida* usually occurs in the lava fields too, but is also frequent on any kind of basalt rock or palagonite tuff. It is probably rare or lacking in some of the more continental valleys of Northern and Northeastern Iceland. But even there it is frequent in the mountains. This agrees with its worldwide distribution, which is considered rather oceanic.

For *T. coarctata* no records are found in the literature from Iceland. Deichmann Brandt (1903) mentioned *Trapelia ornata* (under the name *Lecanora coarctata* var. *ornata)* from Viðvík, Northern Iceland, a species closely related to *T. coarctata.* This, however, does not permit the conclusion, that *T. coarctata* should be lacking or even rare in Iceland, because the information on crustose rock lichens in Iceland is very poor, and dates mainly from the last century. *T. coarctata* prefers damp localities and probably a relatively oceanic climate (Hertel 1969, 1970) and should therefore be expected to occur along the southern coast of Iceland.

ACKNOWLEDGEMENTS

The excursion to Surtsey 1970 was sponsored by the Surtsey Research Society. I would like to express my thanks to Dr. H. Hertel, Berlin, for the identification of *Trapelia coarctata.*

References:

Deichmann Branth, I. S. 1903: Lichenes Islandiae. Bot. Tidsskr. 25, 197–220.

Hertel, H. 1969: Die Flechtengattung *Trapelia* Choisy. Herzogia 1, 111–130.

Hertel, H. 1970: Trapeliaceae — eine neue Flechtenfamilie. Dtsch. Bot. Ges. Neue Folge Nr. 4, 171–185.

Kristinsson, H. 1970: Report on Lichenological Work on Surtsey and in Iceland. Surtsey Res. Progr. Rep. 5, 52.

Preliminary Report on the Surtsey Investigation in 1969 and 1970 Terrestrial Invertebrates

By

CARL H. LINDROTH, HUGO ANDERSSON, HÖGNI BÖDVARSSON, BIRGER PEJLER and SIGURDUR H. RICHTER

Zoological Institute, Universities of Lund and Uppsala, Sweden

FIELD WORK IN 1969

We did not visit Iceland in 1969. However, the well-known naturalist Hálfdán Björnsson, Kvísker, stayed on Surtsey during two periods this summer, from end of April to mid May, and again in September. He made extensive collecting of insects which have been put at our disposal. Stray specimens were captured by other visitors.

As far as identified, the material from 1969 contains 9 species not previously recorded from Surtsey: *Clinocera stagnalis* Hal., *Hydrellia griseola* Fall., *Leptocera lutosa* Stenh., *Parascaptomyza pallida* Zett., Diptera; *Enicmus minutus* L., *Otiorrhynchus arcticus* O. Fbr., Coleoptera; *Plutella senilella* Zett., *Pyrameis cardui* L., Lepidoptera; *Arctocorisa carinata* C. R. Sahlb., Hemiptera.

With these additions the total number of terrestrial Arthropods observed on Surtsey raised to 80 species.

The weevil *Otiorrhynchus arcticus* was of special interest because it is flightless and must have arrived by hydrochorous transport. Three specimens were found on the shore by Hálfdán Björnsson, of which two were dead but one alive. As described in our report for 1968, *Otiorrhynchus arcticus* may be able, under favourable circumstances, to survive exposure to seawater, at least if carried in a grass-tussock. For this reason a series of experiments on the effect of such exposure upon two species af flightless weevils (fam. *Curculionidae)* was performed in August 1970, in Reykjavík. Besides the *Otiorrhynchus,* also *Barynotus squamosus* Germ. was used; these are the two most abundant weevils on Heimaey.

5 *Otiorrhynchus* and 4 *Barynotus* were brought into each of two glass-jars with seawater, of which one was left undisturbed whereas the other was shaken at uneven intervals. After a little more than 24 hours all 8 *Barynotus* and 4 out of 5 *Otiorrhynchus* in the disturbed jar were at the bottom; but all 5 *Otiorrhynchus* in the undisturbed jar were still floating. After shaking, at h 38, also 4 of these sank. All 18 specimens were then dried on filter paper but only 2 *Barynotus* and 1 *Otiorrhynchus* seemed to recover to normal motility, all from the un-shaken water sample. 6 motionless *Otiorrhynchus* (3 from each jar) were watched for another 24 h day without showing any sign of life. The conclusion is that these weevils can hardly endure long-distance sea transport without attaching themselves to floating subjects.

FIELD WORK IN 1970

Our group was extended to include also a micro-zoologist, Dr. Birger Pejler, Uppsala University, who worked in close co-operation with the algologist, Dr. G. H. Schwabe, Plön (West Germany).

The field work was entirely devoted to Surtsey itself and lasted from August 5th through 11th. The weather was exceptionally good.

However, most of the material was brought together through continuous, daily collecting during most of the summer by an Icelandic student, Erling Ólafsson, who served as one of the guards on Surtsey and turned out to be a most skilful and ardent observer and collector.

In 1970 we introduced a new kind of screen-traps for catching flying insects. These are of simple construction and easy to handle but gave a better result than the previously used glue-traps. Our screen-trap consists of a transparent plastic sheet in vertical position. When bumping into this, the insects fall into a tray with water, to which has been added diluted formalin together with some detergent.

Also in 1970 Mr. Hálfdán Björnsson collected on Surtsey, 30.IV.–14.V.

Since the plans for publishing our experiences from the first seven years of Surtsey's existence are well advanced and the resulting book is probably going to appear in 1972, we restrict ourselves in this preliminary report to presenting a list of terrestrial invertebrates not previously observed on the island, and a few concluding remarks.

Additions to the Surtsey list of Terrestrial Arthropods, 1969–70.

INSECTA

Diptera

Fam. Chironomidae

Micropsectra atrofasciata Kieff. 12–14.VIII,70, 3 ex.

M. lindrothi Goetgh. 12.VIII.70.

Tanytarsus gracilentus Holmgr. 13.VIII.70.

Chironomus lugubris Zett. 21.V.70, 3 ex.

Psectroladius limbatellus Holmgr. 22.VIII.70.

Fam. Trichoceridae

Trichocera maculipennis Meig. 27.VI.70.

Fam. Anisopodidae

Sylvicola fenestralis Scop. 1.VII.70.

Fam. Tipulidae

Limonia autumnalis Staeg. 3–5.IX.70, 5 ex.

Erioptera hybrida Meig. 22.VIII.70.

Fam. Empididae

Clinocera stagnalis Hal. 28.IV.–13.V.69, 7 ex.

Fam. Syrphidae

Platycheirus clypeatus Meig. 27.VI.–7.VII.70, 3 ex.

Syrphus ribesii L. 16.VIII.70.

Metasyrphus lundbecki S.–R. 7.VII.70.

Phalacrodira tarsata Zett. 9–14.VII.70, 2 ex.

Melanogyna lasiophthalma Zett. V.VII.70.

Helophilus pendulus L. 11–14.VII.70, 11 ex.

Fam. Sepsidae

Themira pusilla Zett. 16.VIII.70.

Fam. Heleomyzidae

Neoleria prominens Beck. 16.VIII.70, 2 ex.

Fam. Sphaeroceridae

Copromyza nigra Meig. 27.VI.70.

Thoracochaeta zosterae Hal. 27.VI.70, 12 ex.

Leptocera lutosa Stenh. IV.69.

Fam. Ephydridae

Discozerina bohemani Beck. 6–16.VIII.70,2 ex.

Philygria vittipennis Zett. 2.VII.70.

Hydrellia griseola Fall. 12–16.IX.69, 6 ex.; 11.VII.–17.VIII.70, 10 ex.

Scatella stagnalis Fall. 3–8.IX.70, 2 ex.

S. tenuicosta Coll. 20.VIII.70, 2 ex. bred from artificial body of fresh water.

Parydra pusilla Meig. 14.VIII.70.

Fam. Drosophilidae

Scaptomyza graminum Fall. 16.VIII.–3.IX.70. 2 ex.

Parascaptomyza pallida Zett. 16–17.IX.69, 6 ex.; 16.VIII.70.

Fam. Scatophagidae

Scatophaga villipes Zett. 7.VII.–19.VIII.70. 12 ex.

Chaetosa punctipes Meig. 14–15.VII.70, 2 ex.

Fam. Muscidae

Graphomya maculata Scop. 7.V.–16.VIII.70. 13 ex.

Fam. Anthomyiidae

Fucellia maritima Hal. 7.VIII.70, 2 ex.

Fam. Hippoboscidae

Ornithomyia avicularia L. 26.VIII.70.

Hymenoptera

Fam. Ichneumonidae

Meloboris collector Thunb. VII.–IX.70, 8 ex.

Promethes monticola Snell. 23.VII.70.

Campoletis sp. 2.VII.70.

Ophion sp. 18.IV.69, entire but probably dead cocoon, in drift.

Coleoptera

Fam. Coccinellidae

Coccinella undecimpunctata L. 26.VII.70, dead in drift.

Fam. Lathridiidae

Enicmus minutus L. 1969 and 1970, repeatedly in the house.

Fam. Curculionidae

Otiorrhynchus arcticus O. Fbr. V. 69, live specimen; dead, often fragmented specimens found repeatedly in drift 1968–70.

Barynotus squamosus Germ. 7.V.68, dead in drift.

Lepidoptera

Fam. Nymphalidae

Pyrameis cardui L. 11.IX.69, found dead but no doubt arrived alive.

Fam. Tineidae

Plutella senilella Zett. IV., V., IX.69; VIII.70.

Trichoptera

Fam. Limnephilidae

Limnephilus fenestratus Zett. VII.—VIII.70, 3 ex.

L. affinis Curt. 27.VI.70, dead in drift.

Hemiptera

Fam. Corixidae

Arctocorisa carinata C. R. Sahlb. Dead in drift.

Collembola

Fam. Poduridae

Hypogastrura assimilis Krausb. Repeatedly in 1970.

Fam. Entomobryidae

Vertagopus arborea L. IV. and VIII. 70, 35 ex.

ARACHNOIDEA

Araneida

Fam. Linyphiidae

Phaulothrix hardyi Bl. 8—9.VIII.70, 2 ex.

Fam. Erigonidae

Erigone sp. (young). 7.VIII., 22.VIII.70, 2 ex.

Acarida (incl. a few records from 1967 and 1968)

Mesostigmata

Arctoseius cetratus Selln. 10.VIII.70.

Dendrolaelaps oudemansi Halb. 14.VIII., 28.VIII.68.

Euhaemogamasus ambulans Thorell. V.70.

Haplolaelaps suecicus Selln. 7.VIII.70.

Lasioseius sp. 8—10.VIII.70.

Macrocheles subbadius Berl. 16.VIII.70.

Thinoseius fucicola Halb. IV., V.69; VII.—IX.70.

Trombidiformes

Cocceupodes clavifrons R. Can. 7—10.VIII.70.

Proteurenetes agilis Berl. VIII.70.

Pygmephorus mesembrinae R. Can. 11.VII.68, 13.V.69.

Rhagidia sp. 10.VIII.70.

Acaridiae

Caloglyphus regleri E. & F. Türk. 10.VIII.70.

Myianoetus vesparum Scheuch. VI., VIII.67.

Tyrophagus dimidiatus Herm. VII.68, VIII.70.

Ixodides

Ixodes uriae White. 9.VIII.70.

Total number of Terrestrial Arthropods known from Surtsey:
Insecta 112. — Arachnoidea 24. — Together: 136 species.

The entomological work on Surtsey in 1970 has supplied a most valuable material. It is large, in number of specimens as well as of species. For instance, from 1970 we have noted 55 species of Diptera — in spite of the fact that the material of some of the families is at present not, or only in part, identified — against 32 species for the second best year, 1967.

Thanks to the continuous collecting throughout the summer of 1970 it has been possible to correlate more remarkable samples with prevailing weather conditions during certain days. Preliminary analyses of this kind have provided some interesting hints. It is obvious that strong north winds (10-20 m/sec.) produce a particularly large and diversified material of immigrants. On the other hand, strong-flying insects, like many Diptera Brachycera, are also able to arrive by active flight during calm and sunny days.

COLONIZATION

It is highly doubtful whether the species of flies, *Leria modesta* Meig. in the first place, mentioned in the Progress Report III for 1966, did succeed to achieve more than a temporary colonization of Surtsey. They were stated to breed in carcasses on the shore but, due to the steadily increasing use of the beach as a resting place for gulls and other birds, which reached its maximum in 1970, practically all dead fishes and birds are now being devoured.

A more permanent colonization has, however, taken place in at least two species of insects:

(a) *Anisotoma besselsi* Pack. This was the first collembola to be found on Surtsey, in August 1967. It has since become very abundant, 517 specimens being collected in 21 samples. The species now appears to have become stabilized on the beach as a permanent resident. It is a pronounced halobiont and seems to be easily spread along the coasts and to islands, probably on the ocean surface itself. — It is possible that the same applies to *Isotoma maritima* Tullb., found in 10 samples, though with much lower abundance. Its biology is very similar.

(b) *Cricotopus variabilis* Staeg. This is, without any comparison, the commonest chironomid midge both on Heimaey and Surtsey. We were able to state, in August 1967, that the species on Heimaey breeds in rock-pools with high-salinity water. In August 1970 we found three larvae (identified by M. Hirvenoja) on Surtsey in small shallow pools on top of lava blocks close to the tidal zone, both north and southwest of the station. There is no reason to believe that this midge will disappear from the island.

MICROZOOLOGY

In collaboration with Dr. G. H. Schwabe soil samples were taken by B. Pejler from different localities on Surtsey in August 1970, especially on spots where vegetation of mosses and algae was found. After the return to Uppsala, the samples were inoculated, under sterile conditions, into plates with agar substrate and retorts with liquid culture medium. In most of these cultures algae have been developed, often also mosses, and in some microzoa have been found, especially from different localities in the crater of Surtur II, where eight taxa of naked amoebae, two shelled amoeboe, some ciliates and one bdelloid rotifer were encountered. A locality with moss vegetation S of Surtur I contained representatives of all the groups mentioned. Finally, the so-called *Scatella*-locality (in the gorge W of "New Year Crater") housed two naked amoebae and one ciliate. In the basins erected by Dr. Maguire diverse animals were observed; three monogonontous rotifers and one heliozoan were determined to species.

Drs. Elisabet and Lars Eric Henriksson, Institute of Plant Physiology, Uppsala, have investigated the nitrogen fixing of the blue-green algae from the soil samples and are preparing a paper on this subject, together with B. Pejler. One of his students, Mr. Olof Holmberg, is studying the variation, adaption to different substrates, behaviour and food selection of the naked amoebae of the cultures.

PLANS FOR THE FUTURE

It is our intention to visit Surtsey every second year in the future, with the main purpose of following the colonization, notably of developing vegetated spots.

A general idea of factors governing over-seas dispersal in the area seems already to have been achieved.

ACKNOWLEDGEMENT

This work was sponsored by the Surtsey Research Society and the Swedish Natural Science Research Council.

Substrate Temperature Measurements and Location of Thermal Areas on Surtsey Summer 1970

By

SKÚLI MAGNÚSSON, BJARTMAR SVEINBJÖRNSSON and STURLA FRIDRIKSSON*

* The Agricultural Research Institute, Reykjavík, Iceland

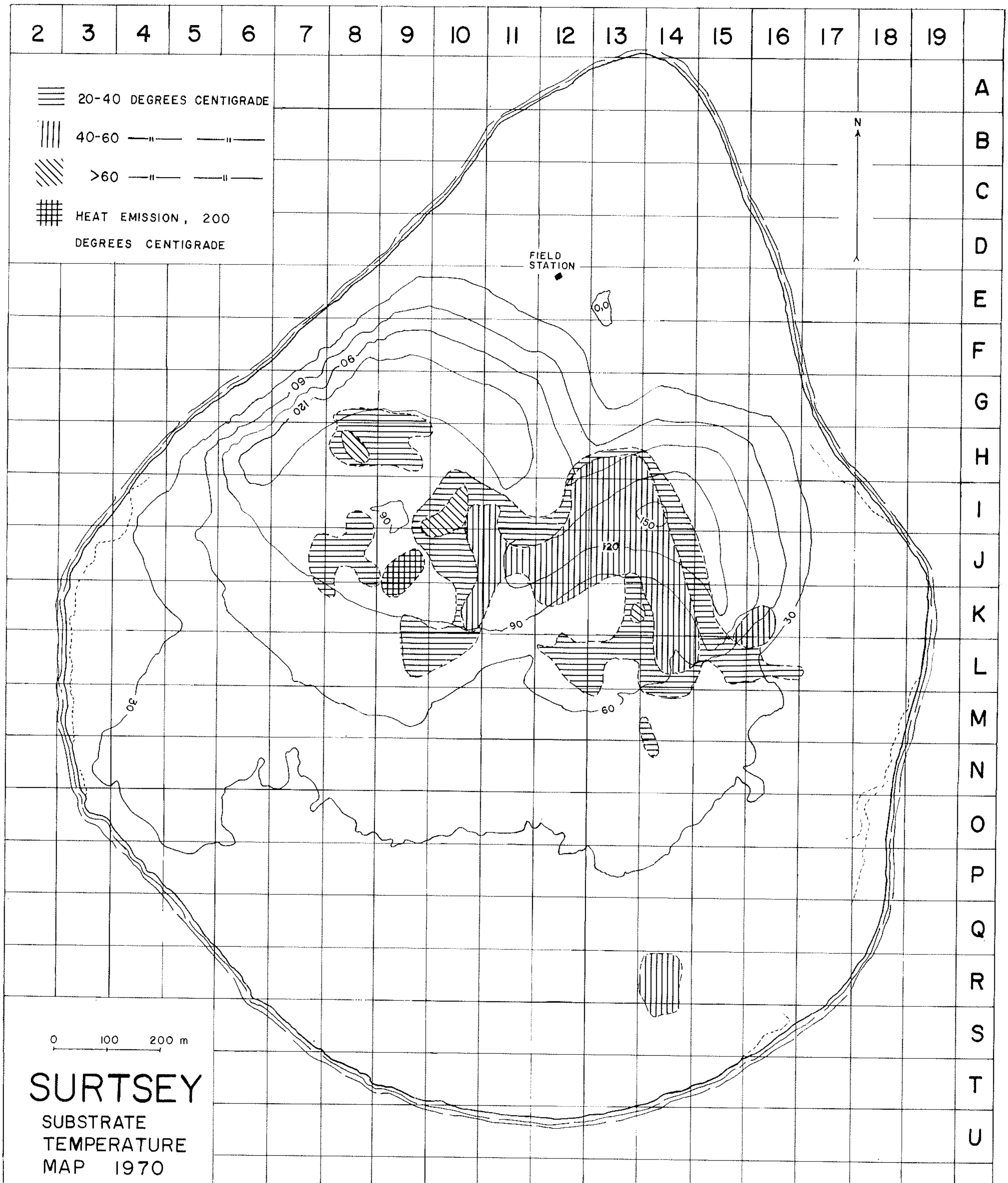
INTRODUCTION

During the summer of 1970, measurements of temperatures of the substrates in Surtsey were taken, at the same time as the plant studies were undertaken. The object of these measurements was to establish the location of the thermal areas, for comparison with the distribution of vegetation on the island.

METHOD OF RESEARCH

A thermometer of the thermistor type was used for the aforesaid measurements. They were taken in all parts of the island and at a depth of 20 cm to avoid effects of air temperature. However, it was not possible to measure at this depth in some areas of lava, as the layer of substrate was to thin, but in those cases the greatest depth available was used.

Fig. 1. Thermal area at the border of lava and tephra north of Surtur II. (Photo by Á. H. Bjarnason.)



In the thermal areas, measurements were made much more densely than elsewhere on the island, in order to facilitate the drawing of isothermal lines with reasonable accuracy and to classify them according to temperature. All measurements were registered on an aerial photograph, and the temperatures marked on charts. The boundaries of the thermal areas were selected at 20°C. Outside the thermal areas the temperature was almost everywhere between 9°C and 14°C.

The following classification was used when making the attached temperature chart:

1. Areas with most measurements between 20° and 40°C.

2. Areas with most measurements between 40° and 60°C.
3. Areas with most measurements above 60°C.
4. Areas with heat emission, measured at 200°C in plots J and K9. The layer of substrate there was very thin.

Sveinn Jakobsson, a geologist from the Icelandic Institute of Natural History, lent the authors the results of similar measurements made by him on the tephra areas. These data were also used in the making of the chart.

DISCUSSION

If the attached chart and the vegetation map of Surtsey from 1970 (Fridriksson et al. 1971) are compared, it will be clearly seen that there is no connexion between the thermal areas having temperatures above 20°C in the substrate and the distribution of the vascular plants, as no vascular plant grows in the areas concerned. However, plants nos. 65, 73 and 74 were right on the fringe of such areas.

On the other hand, moss grows in many places within these thermal areas, and the most fertile area of moss on the island is in fact found there (L-12). The best conditions for the growth of moss are near steam emissions, which are found mostly where the lava and the tephra meet and in Surtur I (L-12). The question as to how far the growth of the mosses near steam emissions is due to the higher temperature has not been investigated, but it is probable that the constant moisture concentrated in these areas is a much more important factor. (Bjarnason and Fridriksson, 1971.)

ACKNOWLEDGEMENTS

The work on which this paper is based was sponsored by the Surtsey Research Society with grant from the U.S. Atomic Energy Commission, Environmental Branch, under the contract No. AT (30–1)–3549.

References:

Bjarnason, Á. and Fridriksson, S., 1971.
Mosses on Surtsey, Summer 1969 –
Surtsey Research Progress Report VI.
Fridriksson, S., Sveinbjörnsson, B., and Magnússon, S., 1971 –
Vegetation on Surtsey, Summer 1970.
Surtsey Research Progress Report VI.

Algae on Surtsey in 1969–1970

By

G. H. SCHWABE and K. BEHRE†

Max-Planck-Institut für Limnologie, D-232 Plön.

In the ecogenesis of this volcanic island two biomes can clearly be distinguished:

1. The marine litoral and sublitorial,
2. The proper surface of the island as a terrestrial region. (Natural inland waters do no longer exist there after two shore-pools have been filled up with wind-shifted tephroite (1967 and 1969) and a rock-pool was destroyed by breakers.)

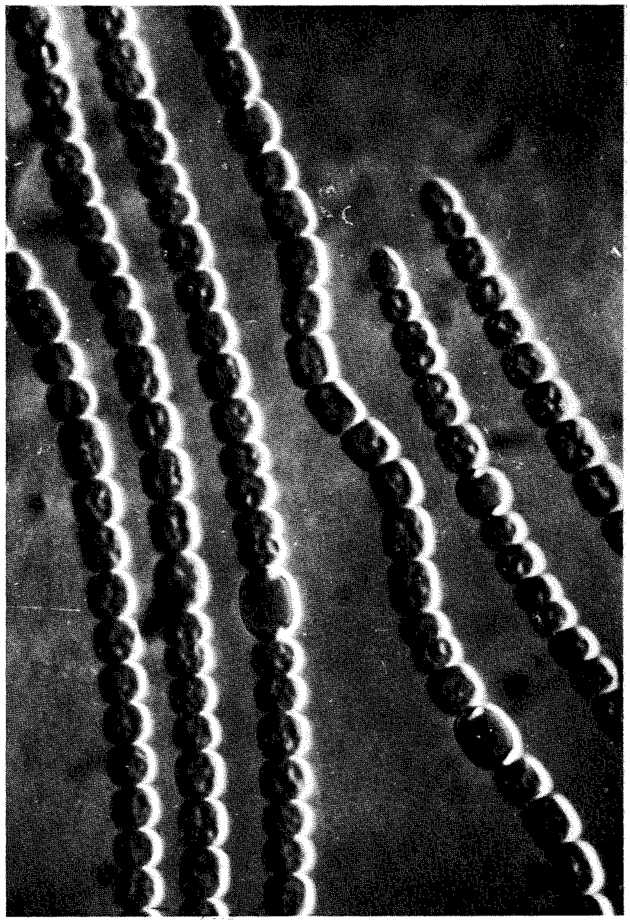
In both of the biomes the early stages of ecogenesis are most clearly marked by cryptogams. The marine litoral and sublitoral, as far as the substrata are fixed, has been covered for several years (S. Jónsson 1970, M. S. Doty 1967) by a rapidly growing vegetation which is rich in species. These populations of algae cover wide continuous areas. In the splashing zone on surface lava early deposits of algae have developed, which no doubt belong to the marine biome.

In contrast to this, the colonization of the terrestrial biome begins in small restricted "oases", remaining limited to these at least until summer 1969. Only later a diffuse colonization can be found which, however, also in summer 1971 is yet restricted to small favourable biotopes. – The striking difference between these two biomes is due to several factors:

1. Below the sea-level and on lava rocks within the reach of breakers the young volcanic material only serves as a substratum for the young vegeation, so that it is only important from a mechanical point of view. The chemical character of the erupted matter does not decisively influence its colonization, especially as a continued change of water dilutes any toxical factors below the tidal zone in a short time. The biotic metabolism there is almost exclusively determined by salt-water. In contrast to this the autotrophic beings in the terrestrial area also with regard to the physiology of their maintenance depend upon the substratum, i. e. they depend on nutritive matter available there and are exposed to its restraining and toxical factors. Atmospheric weathering and tephroite shifted by winds apparently delay considerably the elimination of poisons from the substratum. These problems have not yet been investigated in details.
2. Above the high-water mark and the splashing zone (on surface lava) the development of the vegetation is particularly restricted by a periodical shortage of water, whilst below this level there is no such restriction.
3. The shifting of dry tephroite by wind, which is gradually diminishing, but up to summer 1971 was clearly recognisable, checks in several respects any development of vegetation (partial or complete covering by tephroite, mechanical damages).
4. In the marine area the natural flow of the organisms (perennial germs, propagational organs, cells, vital fragments) which may develop on new substratum, is comparatively much greater than in the terrestrial area, which is ecologically isolated from similar biotopes. This difference is, however, of minor importance in comparison with the above-mentioned factors. The majority of organisms arriving on the surface of the island will be frustrated by the unfavourable ecological conditions there. This is clearly recognizable by a comparison between the areas of colonization (particularly of mosses) and their development between 1968 and 1971.

Due to these conditions the vegetation recognizable with the naked eye (apart from some Phanerogames, which are not discussed here) seems to be restricted – until summer 1969 – to the next surroundings of steam-crevices. This vegetation consists of scarce turfs of mosses and here and there populations of algae, which are just recognizable at favourable lighting as a

Schizothrix lardacea (13.9.69) S. 249/345/16



Anabaena variabilis (4.10.70) S. 327/304/34

greenish sheen on the surface of fine ash which is fasten through humidity. Numerous investigations of substrate samples from all regions of the island (unselective enrichment cultures with substrates from all parts of the island and microscopic controls) confirm that up to that time an active population of algae is restricted nearly without exceptions to these post-volcanic oases of the ecogenesis. But in these places the number of living species is extraordinarily great (in 1968 already more than 100 species). Just a few meters distance from these places either no algae at all or only single species are found in the raw cultures. It is very probable that these single findings have come out of the resting stages, which originate from the oases and were removed by wind, and more seldom by water.

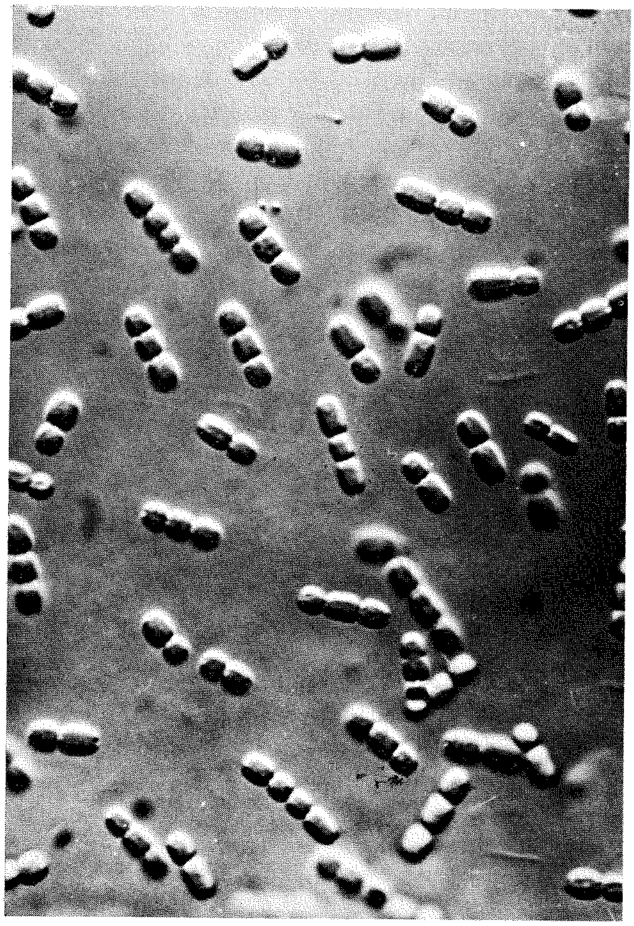
The hitherto existing results of the 1969 and 1970 investigations show above all two processes:

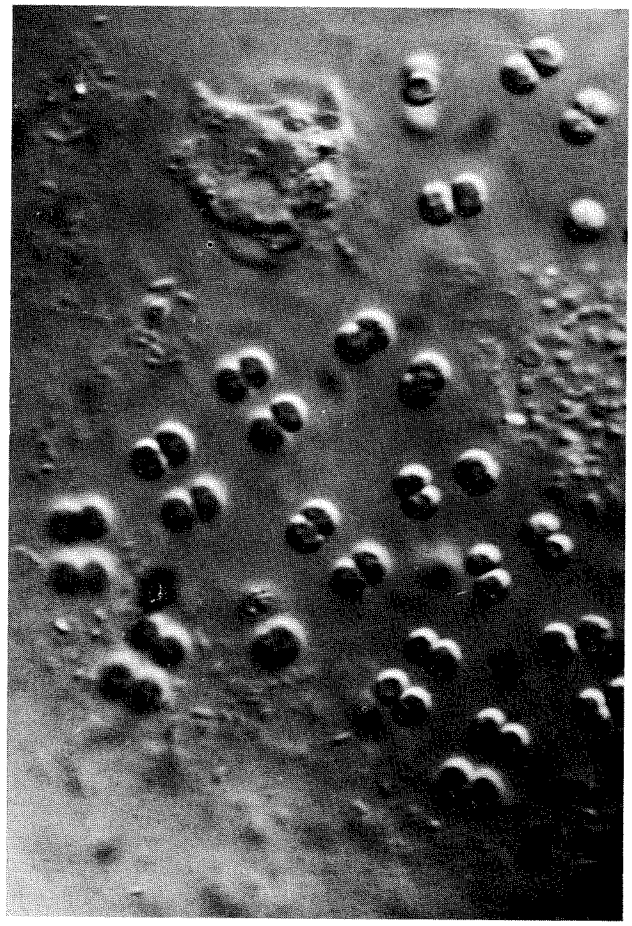
1. A quick increase in number of species, especially in the oases,
2. The beginning of active population in places which are outside of the influence of steam and, moreover, are microclimatically favoured.

As the taxonomic analysis of the extensive material is not completed, no exact data can be given. In 1970 the active population of the island by algae (i. e. the quantity of algae developing and increasing there) will surely turn out manifold in number of species compared to what it was in 1968.

This microflora is largely identical with the algae-flora of Icelandic raw soils, but represents a selection of small and smallest forms. Such an assortment leads to the assumption that it is mainly the atmosphere (transportation by wind) which carries the populating species to Surtsey; this hypothesis is supported by various observations:

1. Substrata exposed on the steeple of Landakot-church in Reykjavík (summer 1970) hitherto contained a. o. at least 3 species which frequently appear as pioneers at Surtsey.
2. Those oases most exposed to wind (the upper by-craters in Surtur I and especially Strompur) show an extremely high number of species. (These places are relatively seldom visited by visitors to Surtsey, so that just here an anthropogene importation is hardly probable.)


Phormidium mucicola (2.12.70) S. 311/418/9


Aphanocapsa grevillei (12.9.70) S. 299/401/11

The strong enrichment in algal flora in the last years is probably less due to the increase in number of immigrants, but to increasing favourable conditions for colonization offered by the substrates on Surtsey through transformation, binding and weathering. Through alteration by wind and local accumulations of fine fractions of ash, which is especially the case in the unevenness and deepenings of the lava planes, the storing of rain water (protected against quick evaporation) is favoured in certain places. Here, the development of moss turfs is directly striking. Apart from Rhacomitrium, which — as was reported from Iceland — seems to prevent any development of algae, all moss locations on Surtsey were populated by soil algae (especially Anabaena variabilis is very frequently represented).

The diffuse expansion (phase of the diffuse ecogenesis), which has been striking since summer 1970, but was already recognizable during investigation of the algae in summer 1969, is most clearly shown through distribution of the moss turfs whose single parts only seldom surpass some few square centimeters. Until summer 1971 such turfs have only been found in places which are well supplied with water (clefts, cracks and deepenings in the lava where fine ash accumulated or excavations with sufficient light, which are protected against air movements). On the other hand, however, areas exposed to full sun radiation and wind and as well to the south are avoided. The spreading of algae does not confirm these findings anymore with the applied methods, because obviously cells of algae capable of living have already been spread all over the island by wind, and thus practically all superficial substrate samples give positive culture results. But the surroundings of steam exits still turn out to be richest in regard to number of species and to population density.

But on the other hand just those oases which developed at lava cracks are exposed to characteristic damages and back-strokes. The steam cracks are formed and deepened through proceeding cooling of the lava (contraction cracks). Therefore the development of vegetation is favoured over years as long as under these conditions a relatively continuous supply of water is secured through condensation of steam. Although at times an intensified output of steam enhances the local filling and binding of drifting ash and along with it buries the cryptogame vegetation, but generally the mosses grow over such overlaps and at the same time the movable algae forms seem to overcome actively such layers (especially Cyanophytes and Diatoms). Just in one special case could we observe the almost complete destruction of a steam biotop rich in species and extended over some square decimeters (middle by-crater around Surtur I, between 1968 and 1970, "chair"), owing to drift. In general the oases areas are enlarged through intensified output of steam.

If on the contrary — e. g. due to less rain falls as in early summer 1971 — the supply of water to the cracked regions is diminishing, the temperatures of the outcoming air-steam-mixture rise, at the reduced percentage of steam, to such an extent that there will be no more condensation and the surface temperatures may rise above the boiling point. In summer 1970 the area most exuberant in mosses in Surtur II (more than 100 m^2) had been encircled with a hemp cord and marked. One year later the whole visible vegetation was destroyed and the cord was burnt at several spots. After an early summer poor in rain fall the only obvious reason for this backstroke, which is regionally limited but characteristic for steam-cracks, seems to be in reduced supply of water at continuous deepening of the contraction cracks, which led consequently to a drying-up and over-heating of the populated areas.

In the same period, however, further diffuse colonization took place in post-volcanic non-active regions, especially on the lava-planes. A considerable quantity of the "seed-corn" which developed there, very likely seems to orginate from the vegetations of the pioneer oases which are meanwhile again partially destroyed. Thus, the ecogenesis is a process going on discontinually in its single steps. And moreover, another proof seems to be given by the population dynamics under the influence of new immigrants.

In August 1971 Dr. Karl Behre, Bremen, gives the following report on his observations hitherto made for the years 1969 and 1970 (soil algae, without Cyanophytes):

"The investigations started in 1968 were continued on broader basis. Whereas, there were only 11 samples in 1968 which have been collected almost exclusively from the craters Surtur I and Surtur II, while 31 samples in 1969 and 47 samples in 1970 collected from the different parts on the island, were also investigated.

Soon after in 1968 the typical soil forms of the Diatoms had been strongly represented, this happened with other algae groups as well or they became predominating where as before they were represented by smaller numbers.

The Heterocontae increased from two forms in 1968 to almost a dozen in 1970, among them were several species of *Heterothrix (H. exilis,* one of the most frequent soil algae, *H. tribonematoidea, H. montana).* In 1970 *Tribonema* joined with *T. elegans* and *T. minus.* The presumably cosmopolitan soil algae *Monodus subterranca* now appeared in 14 samples. One moss sample contained *Characiopsis minor* in all three investigated cultures, which up to now had not been reported as soil algae, but lived in large quantities on the humid mosses.

The Eugleninae kept their low initial frequency, *Euglena mutabilis* was found every year in one or two samples, besides a second *Euglena* species and some species of Petalomonas and *Notosolenos* were very sporadic. Specially in the last years few individuals of certain colourless flagellates, primarely *Rhynchomonas nasuta* and several *Cercobodo*-species, were also repeatedly found.

In the following two years almost 20 forms of *Chlamydomonas* were found, which already in 1968 showed a striking frequency of 8 species; about one dozen could be put near to known species (these were: *C. moewusii, C. moewusii* v. *major, C. oviformis, C. debaryana* v. *micropapillata, C. petasus, C. rotula, C. asymmetrica* v. gallica and v. minima, C. intermedia). The two species C. foraminata and C. pseudintermedia newly described for 1968, have also been well represented in the following time, in 6 samples in 1970. Now, the first Carteria appeared in few specimen.

Already in 1968 the Chlorococcales were represented by the soil alga *Chlorella.* Together with four different forms of the three species *C. vulgaris, C. saccharophila* and *C. minima* it belonged in 1969 to the predominating soil algae which were found in nearly every sample. 1970 showed a slight reduction, but *C. vulgaris* still appeared in 18 samples. — Since 1969 *Chlorococcum* and related genera appeared in a number of problematic forms which up to now could not be determined. — *Scenedesmus* appeared — especially with S. ecornis (in three samples) — for the first time in 1969, whereas in 1970 the most frequent form (in four samples) was approximately correspondant to *S. chlorelloides.* Further, *S. acutiformis* and *S. microspina* were found. — One sample frequently contained the soil alga *Dictyosphaerium minutum* which had rarely been found up to that time.

Meanwhile the filiform green algae, which were almost completely lacking at the beginning, have strongly developed. *Chlorhormidium flaccidum* with 6 samples in 1969 and 26 samples in 1970 can be regarded as the most frequent soil algae on the island. *Chlorhormidium pseudostichococcus* was represented with 7 samples in 1969 and with 4 samples in 1970. *Gloeotila protogenita,* found in Surtur I, however, decreased from 4 samples in 1968 to 2 samples in 1970, which — as must be admitted — this time were collected from different places on the island. *Stichococcus* minor and *S. bacillaris* s. ampl. increased from 1 (respectively 2) to 8 (3) samples with the particularity that they preferred isolated localities (outside of Surtur I and II).

Generally Desmidiaceae are not known as air algae. Nevertheless in 1969 *Closterium pusillum* and *Mesotaenium macrococcum* appeared in some samples. In 1970 an Actinotaenium joined, and *C .pusillum* was reported in 9 samples from 4 different localities on the island.

As the preparation of the diatoms for finer investigation could not yet be done, this group is only considered as far as the forms are recognisable in fresh state. — The 4 "soil algae par excellence" *Navicula atomus, N. mutica, Pinnularia borealis* and *Hantzschia amphioxys* had already been found in 1968 and are still there: the first 2 belonging to the most frequent algae, *Pinnularia borealis* from the beginning only in few samples, *Hantzschia amphioxys* ranging amongst the top group in 1968, but only found in few specimen in 1969 and then again contained in 11 samples in 1970. This fluctuation is surprising, but there is no possible doubt about it, as this alga can easily and surely be recognized with the dry system. It is further remarkable to see the strong development of *Nitzschia fonticola,* which was found in 1968 in one specimen in each of the two craters, and appeared in 1969 in 5 and in 1970 in 13 samples. *Pinnularia intermedia,* found in 4 samples from Surtur I in the year 1968, appeared in the fresh 1969 material only in the 5 cultures of one sample near the western shore of the island, and in 1970 in 7 samples it was spread over the whole island. During these 3 years *Navicula* cf. *dismutica* remained in the single samples, but these ones coming from completely different places on the island. During 1970 *Achnanthes coarctata* appeared in 3 samples from different places on the island. — As a whole the number of species of diatoms seems to have decreased a bit in 1969, but increased again in 1970.

In the last two years there were no more ecological differences between the craters Surtur I and II (different humidity), the algae were now equally distributed over these 2 — always still very rich — localities. But at the same time there appeared forms, from the most different places on the island, which up to now have not been observed in regard to the regularity in their distribution, so as to make any definite statements here."

The analysis of the "soil algae" in the last three years gave a. o. the surprising result of a relatively great number of rare or — up to that time — completely unknown species. These findings cannot satisfactorily be explained with a merely insufficient general knowledge of these groups. The relative frequency of some of such novices is a counter-argument to such an interpretation (besides other concomitant circumstances). So, at least for the present we can assume that under the local special conditions some species can develop, which somewhere else, i. e. in older "matured" biotopes, would not stand the competition they meet there and may even be able (for instance as sprinkles into other populations) to reach a stage of spreading where they can predominate in new territory still free of competition (in non-occupied niches) or even develop "pure populations". Without such assumptions, for example, the existence of two hitherto unknown Nostocaceae — both are distinctly thermophilic — can hardly be understood.

References:

Behre, K. u. G. H. Schwabe, 1970: Auf Surtsey/Island im Sommer 1968 nachgewiesene nicht marine Algen. — Schr. Naturw. Ver. Schleswig-Holst.: Sonderband Surtsey 31-100

Doty, M. S., 1967: Contrast between the Pioneer Populating Process on Land and Shore. — Bull. So. Calif. Acad Sci. *66:* 175—194.

Jónsson, Sigurdur, 1970: Meeresalgen als Erstbesiedler der Vulkaninsel Surtsey. — Schr. Naturw. Ver. Schleswig-Holst.: Sonderband Surtsey 21—28.

Schwabe, G. H., 1971: Die Ökogenese in terrestrichen Bereich postvulkanischer Substrate. (Schematische Übersicht bisheriger Befunde auf Surtsey (Island). — Peterm. Geograph. Mitt. (4) 268—273.

—. 1971: Surtsey, — Kosmos *67* (12) 489—497.

Schwabe, G. H. u. K. Behre, 1971: Ökogenese der Insel Surtsey 1968—1970. — Naturwiss. Rdsch. *24* (12) 513—519.

Surtsey Research Progress Report V, 1970: Reykjavik.

Microbial Activity on Surtsey*

By
W. SCHWARTZ and ADELHEID SCHWARTZ

During a stay of a few days on Surtsey in 1969, tephra and volcanic ashes were collected by W. Schwartz for a microbiological examination. Cholodny slides were exposed for 2 to 3 days and different possible biotops have been distinguished:

Fumaroles with vents and high production of H_2O, steady at least for some time (group F), – fumaroles with low activity but still higher temperatures and humidity in the tephra (groups Lz and partly Te), – volcanic ashes, glas, tephra without visual signs of fumarole activity (group Te), – surface of the lava streams and the rocks of the Surtur craters (group Ld, not yet explored), – tuff walls (group Tw), and the pond and its sediments (group W).

Highest germ numbers, mostly of bacteria, have been found in the surroundings of the fumaroles where temperature and humidity are favourable for the development of microbes.

The numbers of aerobes were between 10^4 and 10^7, of anaerobes between 10^2 and 10^4/g. Most of the anaerobes were facultative ones. Strains of the genera Corynebacterium, Arthrobacter, Bacillus, Flavobacterium, Pseudomonas, Micrococcus have been identified. Streptomyces strains were present only in low numbers. Tests for specific biochemical groups gave negative results for desulphurizers, Azotobacter, and Cl. pasteurianum. Thiobac. thiooxidans and ferrooxidans were present only in 1 sample of the F-group at a time. Denitrifyers and the bacteria of nitrification were more frequent. The results are compared with the exploration of cinder cones on Deception Island, Antarctica by CAMERON and BENOIT (Ecology *51*, 1970, 802–809) and a program for the further microbiological exploration of Surtsey is outlined.

---

* A detailed paper is under press in Zeitschrift für Allgemeine Mikrobiologie.

The Benthic Coastal Fauna of Surtsey in 1969

By

ADALSTEINN SIGURDSSON

Reykjavík, Iceland.

INTRODUCTION

The sampling of benthic animals in the littoral and sublittoral zones of Surtsey was continued in a similar way in 1969 as in the year before (Sigurdsson 1970).

As previously the crew of M/S "Sæör" carried out the submarine work in the subtidal zone with active interest.

Due to shortage of time the Danes could not be contacted this year (Sigurdsson 1970).

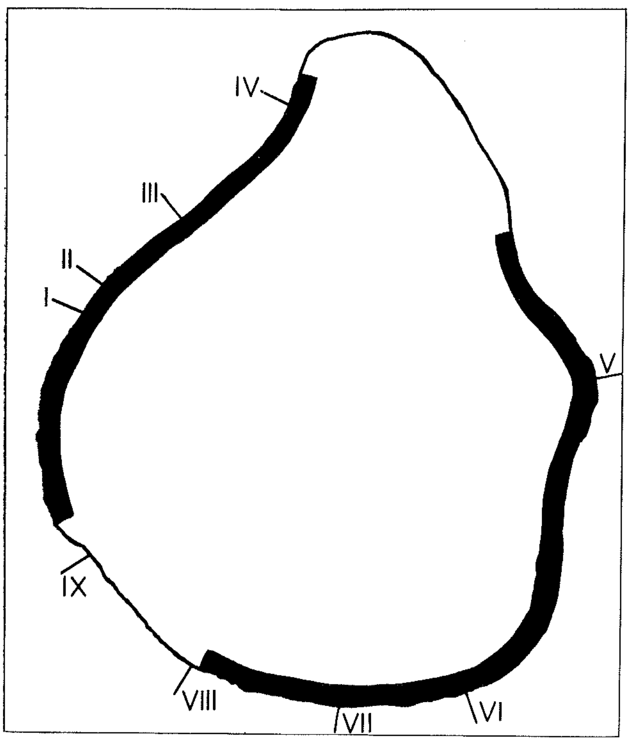


Fig. 1. Map of Surtsey showing the location of traverses I—IX. The thick line indicates the streches surveyed on the shore. For comparison with the samples from 1968, the following shoud be noted: Traverse I = "Off the Northern Part of the Lava Field (W.)" (Sigurdsson 1970, Table 2). Traverse II = "The Boundaries of Sand and Hard Bottom (W.)" (l.c. Table 2). Traverse V = "Off the North-East Cliffs" (l.c. Table 4). Traverse VI = "Off the South-East Cliffs" (l.c. Table 3). Traverse VIII = "The South Coast" (l.c. Table 3).

SAMPLING

The surveys of the tidal zone were made on April 16, May 2, and from July 29 to August 2 (Table 1). Due to a heavy swell the samples from the east and south coasts contain only animals from the upper region of the littoral zone.

The sampling in the sublittoral zone was carried out on traverses I—IX from July 21 to 24 (Fig. 1). The depth range is shown in tables 2—5.

All the traverses were worked from a depth of 20 or 40 metres and as close up to the shore as possible, but because of surf the SCUBA-divers usually could not reach the shore, and on traverses VII and VIII they could not work at less than 20 metres' depth on account of the heavy swell.

On traverse IV the bottom was sandy, but on all the others it was hard and of a similar character. Close to the shore were rounded basalt blocks over 1 metre in diameter, most often with sand and gravel in between, changing to still bigger blocks up to 3 metres in diameter with less or even no sand and gravel at 15 metres' depth. From 15—20 metres' depth the rocks again decreased in size downwards with some sand appearing in between. At 30 metres' depth the blocks were bedded in sand and at traverse VIII they were no longer rounded. At a depth of 40 m there was only sand, except on traverse VIII, where scattered stones were found as well.

RESULTS

The identification of the specimens is still somewhat incomplete, and as the Danish biologists could not be contacted, the author is solely responsible.

Tables 1—5 show the distribution of benthic animals at Surtsey. The samples are not quantitative, but the number of animals (Tables 2—5) should, however, give a rough idea of their

TABLE 1

Animals from the littoral zone of Surtsey in 1969.

	April 16	May 2		July 29 — August 2		
	West Coast	West Coast	[1])Northwest Coast	West Coast	East Coast	South Coast
HYDROZOA	×	..	..	×	×	×
POLYCHAETA	6	17	..	8	9	14
BRYOZOA	×	×	..	×	..	..
COPEPODA	..	..	..	70	50	1
CIRRIPEDIA:	..	..	..	..	..	..
Verruca stroemia (Müller) Schum.	2	18	..	..	11	2
Balanus balanoides (L.) Bruguière	1	4	..	120	26	9
DECAPODA:	..	..	..	..	..	..
Portunus holsatus Fabr.	..	..	1	..	..	..
NUDIBRANCHIA	..	..	..	2	..	..
LAMELLIBRANCHIA:	..	..	..	..	..	..
Heteranomia squamula (L.)	3	5	..	2	..	..
Mytilus edulis L.	8	14	1	12	4	1
Saxicava arctica (L.)	30	50	..	6	..	..
ASTEROIDEA:	..	..	..	..	..	..
Asterias rubens L.	..	..	1	..	..	..

[1]) Drifted ashore.

TABLE 2

Animals from the subtidal zone of the west coast of Surtsey in 1969. Traverse I (see Fig. 1)

	July 22					
	5-10 m	10-20 m	15 m	20 m	28-30 m	40 m
HYDROZOA	..	×	×	×	×	..
ANTHOZOA:	..	..	..	..	..	..
Alcyonium digitatum L.	..	..	..	×	×	..
POLYCHAETA	1	4	5	11	25	27
BRYOZOA	..	×	..	..	×	..
COPEPODA	..	..	..	..	1	..
CIRRIPEDIA:	..	..	..	..	..	..
Verruca stroemia (Müller) Schum.	..	..	×	..	Shell	..
**Balanus balanus* (L.) da Costa	..	..	..	..	Shell	..
Balanus balanoides (L.) Bruguière	1	2	..	..	..	..
Balanus sp. juv.	..	..	1	1	1	..
AMPHIPODA	5	6	75	11	1	..
DECAPODA:	Zoea	..	..	..	..	..
Hyas coarctatus Leach	..	4	3	5	9	..
Portunus holsatus Fabr.	..	..	..	1	..	..
**Galathea nexa* Embl.	..	..	1	1	8	..
PROSOBRANCHIA:	..	..	..	..	..	..
Lacuna divaricata (Fabr.)	..	..	1	..	..	..
NUDIBRANCHIA	..	..	..	1	3	..
LAMELLIBRANCHIA:	..	..	..	..	..	..
Heteranomia squamula (L.)	..	Shells	Shell	Shells	1	..
Chlamys distorta (da Costa)	..	..	..	..	Shells	..
Mytilus edulis L.	..	70	80	100	50	..
Saxicava arctica (L.)	..	9	2	9	27	..
ASTEROIDEA:	..	..	..	..	..	..
Asterias rubens L.	..	..	..	..	1	..
OPHIUROIDEA	..	..	..	..	..	2

* New for Surtsey.

TABLE 3

Animals from the subtidal zone of the northwest coast of Surtsey in 1969. Traverses II to III (see Fig. 1)

	Traverse II Off the N.W. corner of the lava field July 23			Traverse III Off the tephra cliffs of the west coast July 24			
	5-10 m	10-15 m	15-20 m	3-10 m	10 m	13-15 m	18-20 m
HYDROZOA	×	×	×	×	×	×	×
SCYPHOZOA:	..	..	..	..	..	..	..
**Halyclystus octoradiatus* (Lamarck)	..	..	..	1	..	..	..
NEMATODA	..	..	..	..	..	1	..
POLYCHAETA	5	10	37	9	1	18	34
BRYOZOA	..	..	×	..	..	×	..
COPEPODA	..	40	10	20	3	7	3
CIRRIPEDIA:	..	..	..	..	..	..	..
Verruca stroemia (Müller) Schum.	1	..	..	7	..	..	..
Blanus balanoides (L.) Bruguière juv.	..	..	27	..	..	..	..
AMPHIPODA	50	1600	100	60	48	140	49
EUPHAUSIACEA	1	..	..	..	..	..	..
DECAPODA:	..	..	..	..	..	..	..
Hyas coarctatus Leach	..	2	9	2	5	3	6
**Galathea nexa* Embl.	..	..	2	1	..	1	2
Spirontocaris pusiola Kr.	..	..	..	..	..	1	..
PROSOBRANCHIA:	..	..	..	..	..	..	..
Lacuna divaricata (Fabr.)	..	6	2	2	Eggs	3	3
**Odostomia unidentata* (Mont.)	..	..	Shell	..	..	..	..
NUDIBRANCHIA	..	..	..	1	..	..	Eggs
LAMELLIBRANCHIA:	..	..	..	..	..	..	..
Heteranomia squamula (L.)	..	..	2	..	..	Shells	..
Mytilus edulis L.	4	13	80	27	60	350	190
Saxicava arctica (L.)	..	1	20	5	3	14	16
ASTEROIDEA:	..	..	..	..	..	..	..
Asterias rubens L.	..	1	×	..	..	..	..
PISCES:	..	..	..	..	..	..	..
**Cyclopterus lumpus* L. juv.	..	2	..	..	..	..	..

* New for Surtsey.

abundance. × indicates animals present in the samples, but not easily counted, especially those which live in colonies. Of those the hydrozoans are very abundant, the others being less so or even very rare, as for instance the *Porifera*.

Of the animals which have been positively identified, eight species are new for Surtsey, but they are all known from the Vestmannaeyjar archipelago. Moreover the only species of *Porifera* found so far is new for Surtsey. These are marked with asterisks (*) in Tables 2—5.

The absence of four species found in the samples from 1967 and 1968 should be noted (Sigurdsson 1968 and 1970). These are: *Aporrhais pes-pelecani* (L.), *Mya truncata* (L.) (named "bivalve juv." in Table II, Sigurdsson 1968), *Syndosmya nitida* (Müller) and *Ammodytes lancea* Cuvier. The last one is certainly an inhabitant of the sandy bottom at Surtsey from where only few samples were taken in 1969. On the other hand, the three species of molluscs are not likely at present to find suitable substrate for colonization at Surtsey, as all of them are inhabitants of muddy bottom. *Aporrhais pes-pelecani* and *Syndosmya nitida* do, however, live on even bottoms around Surtsey; their larvae being pelagic, young individuals of these species are likely to appear now and then at Surtsey.

Shells, whole and fragmentary, of *Aporrhais pes-pelecani* have been found in the tephra on Surtsey obviously brought up from the bottom of the sea by the eruption, see also Alexandersson 1970.

Fig. 2 shows rough outlines of the vertical distribution of the more abundant benthic animals at Surtsey in July and August 1969. The diagrams are based on the numbers in Tables 1—5, supplimented by the diver's descriptions of the

TABLE 4

Animals from the subtidal zone of the east coast of Surtsey in 1969. Traverses V to VI (see Fig. 1)

	Travers V Off the N.E. cliffs July 21				Travers VI Off the S.E. cliffs July 21		
	5 m	10 m	15 m	19-23 m	7-10 m	15 m	20 m
**PORIFERA*	..	..	..	..	..	..	×
HYDROZOA	..	×	×	×	..	×	×
ANTHOZOA:	..	..	..	..	..	..	..
**Alcyonium digitatum* L.	..	..	..	..	..	..	×
NEMATODA	..	2	..	..	..	..	..
POLYCHAETA	..	20	28	16	3	19	60
BRYOZOA	..	×	×	×	..	..	×
COPEPODA	..	8	1	2	..	20	..
CIRRIPEDIA:	..	..	..	..	..	..	..
Verruca stroemia (Müller) Schum.	..	2	1	1	..	..	49
**Balanus balanus* (L.) da Costa	..	..	..	Shells	..	..	2
Balanus balanoides (L.) Bruguière	..	3	..	..	2	2	..
Balanus hammeri (Ascanius) Brown	..	..	1	3	..	..	1
Balanus sp. juv.	..	..	..	..	..	..	1
AMPHIPODA	1	260	15	19	44	120	17
DECAPODA:	..	..	..	..	..	..	..
Hyas coarctatus Leach	..	2	1	2	..	2	1
**Galathea nexa* Embl.	..	1	..	..	1	..	..
PROSOBRANCHIA:	..	..	..	..	..	..	..
Lacuna divaricata (Fabr.)	..	1	1	1	..	1	..
NUDIBRANCHIA	..	4	..	..	..	4	..
LAMELLIBRANCHIA:	..	..	..	..	..	..	..
Heteranomia squamula (L.)	..	Shells	Shells	5	..	1	11
Chlamys distorta (da Costa)	..	..	1	..	..	..	..
Mytilus edulis L.	..	140	140	120	..	60	320
Saxicava arctica (L.)	..	10	23	19	..	5	27
ASTEROIDEA:	..	..	..	..	..	..	..
Asterias rubens L.	..	1	1	1	..	..	1
ASCIDIACEA juv.	..	..	1	..	..	..	1
PISCES:	..	..	..	..	..	..	..
**Liparis* sp. juv.	..	..	1	..	..	..	..
Limanda limanda (L.)	..	..	..	..	1	..	..

* New for Surtsey.

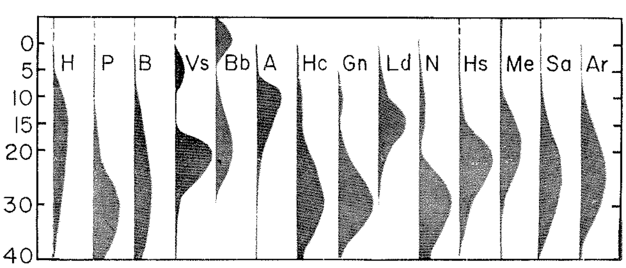


Fig. 2. The vertical distribution of the more abundant benthic animals at Surtsey in 1969. H. = *Hydrozoa*, P. = *Polychaeta*, B. = *Bryozoa*, V.s. = *Verruca stroemia*, B.b. = *Balanus balanoides*, A. = *Amphipoda*, H.c. = *Hyas coarctatus*, G.n. = *Galathea nexa*, L.d. = *Lacuna divaricata*, N. = *Nudibranchia*, H.s. = *Heteranomia squamula*, M.e. = *Mytilus edulis*, S.a. = *Saxicava arctica* and A.r. = *Asterias rubens*.

life on the bottom at the time of sampling. The diagrams do not represent quantitative interrelation between the different species or groups of animals, and each diagram should, therefore, be studied separately.

The vertical distribution of the more rarely-found benthic animals is indicated in Table 6.

In August 1968 the deposit of basalt blocks on the sea floor did not seem to reach farther north along the west coast of Surtsey than traverse II where considerable amount of sand was observed.

By July 1969 the bottom had changed very much and big blocks of rock had replaced the sand. Therefore, traverses III and IV were worked to find out how far north the change had

TABLE 5

Animals from the subtidal zone of the east coast of Surtsey in 1969. Traverses VII to IX (see Fig. 1)

	Traverse VII The Easterly South Coast July 24	Traverse VIII The Middle of the South Coast July 23			Traverse IX The Westerly South Coast July 22		
	20 m	20 m	30 m	40 m	8-10 m	15 m	20 m
HYDROZOA	×	×	×	×	×	×	..
POLYCHAETA	25	15	160	60	3	2	27
BRYOZOA	×	×	×	×	..	..	×
COPEPODA	6	4	..	37	..	..	..
CIRRIPEDIA:	..	..	..	..	..	..	..
Verruca stroemia (Müller) Schum.	4	4	2	1	..	..	..
Balanus balanoides (L.) Bruguière	3	..	..	..	..	..	1
Balanus sp. juv.	..	..	1	2	..	..	..
AMPHIPODA	38	24	7	6	29	..	8
DECAPODA:	..	..	..	..	..	..	..
Hyas coarctatus Leach	17	6	15	4	3	1	2
Portunus holsatus Fabr.	..	..	..	..	..	..	1
**Galathea nexa* Embl.	4	..	4	1	2	..	3
Spirontocaris pusiola Kr.	..	..	4	..	..	..	2
NUDIBRANCHIA	2	Eggs	4	Eggs	..	..	..
LAMELLIBRANCHIA:	..	..	..	..	..	..	..
Heteranomia squamula (L.)	..	..	1	..	..	1	1
Mytilus edulis L.	180	90	9	2	5	100	90
Cardium fasciatum Mont.	..	..	Shell	..	..	..	..
Saxicava arctica (L.)	30	19	7	1	1	9	9
ASTEROIDEA:	..	..	..	..	..	..	..
Asterias rubens L.	1	..	1	..	..	..	..
ASCIDIACEA:	..	1 juv.	..	..	..	..	..
**Styela rustica* (L.)	..	..	..	..	..	..	1
PISCES:	..	..	..	..	..	..	..
**Liparis* sp. juv.	..	..	1	..	..	..	..

* New for Surtsey.

extended. Ca. 300 metres north of travers II, at traverse III, the bottom was paved with huge rocks and was almost without sand at a depth between 5—20 metres, and there were already a rather rich fauna and flora. Of the animals the common mussel and hydrozoans were especially abundant at depth between 10—20 metres just as at other locations with the same type of bottom. The mussels were very small with the exception of one specimen which was more than one year old. Almost all the others had one clear winter ring, but they had obviously been very small at the time of suppression of growth during the winter of 1968—69, which indicates very late spatfall, most likely taking place in early winter. This was not observed in other samples from Surtsey in 1969. As the yearly range of the surface temperature in this region is from 6—12°C (Malmberg 1962 and Stefánsson 1966), the temperature by itself would not prevent successful spatfall in early winter. There might, of course, have been some basalt blocks in this region in the summer of 1968, but it is more likely that most of them were carried north along the coast during the autumn storms in 1968, after which the successful mussel spatfall has occurred. If there had been any considerable population of mussels at this location prior to the autumn of 1968, more than one individual in the samples should have been over one year old. This indicates, therefore, how quickly the animals and plants can colonize a new area.

On traverse IV the bottom was sandy and the only animals found in a sample of sand brought up from 20 metres' depth were 2 polychaete larvae and a single copepod.

ACKNOWLEDGEMENTS

This research has been a part of the Surtsey Research Society's program and in 1969 it was also sponsored by the society. This is highly appreciated.

Thanks are also due to all the others who have assisted in carrying out the research program.

TABLE 6

The vertical distribution of the more rarely found benthic animals

Depth in metres	Porifera	Alcyonium digitatum	Halyclystus octoradiatus	Nematoda	Balanus balanus	Balanus hammeri	Portunus holsatus	Spirontocaris pusiola	Odostomia unidentata	Chlamys distorta	Cardium fasciatum	Ophiuroidea juv.	Ascidiacea juv.	Styela rustica	Cyclopterus lumpus juv.	Liparis sp. juv.	Limanda limanda
	..	..	..	..	..	..		..	..	..	..	..	..	..	..	..	..
							+										
0	..	..	..	..	..	..		..	..	..	..	..	..	..	..	..	..
5	..	..		..	..	..	..	..	..	..	..	..	..	..	..	..	..
			+														
10	..	..		+	..	..	..	+	..	..	..	..	..	..		..	+
															+		
15	..	..	..	..	..	+	..	..		+	..	..	+	..		+	..
									+								
20	+	+	..	..	+	+	+	+		..	..	..	+	+	..	..	..
30	..	+	..	..	+	..	..	+	..	+	+	..	..	..	..	+	..
40	..	..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..

References:

Alexandersson, T., 1970: The Sedimentary Xenoliths from Surtsey: Marine Sediments Lithified on the Sea-Floor. A Preliminary Report. Surtsey Research Progress Report V.

Malmberg, Svend-Aage, 1962: Schichtung und Zirkulation in den südisländischen Gewässern. Kieler Meeresforsch. XVIII, 1.

Sigurdsson, A., 1968: The Coastal Invertebrate Fauna of Surtsey and Vestmannaeyjar. Surtsey Research Progress Report IV.

Sigurdsson, A., 1970: The Benthonic Coastal Fauna of Surtsey in 1968. Surtsey Research Progress Report V.

Stefánsson, U., 1966: Influence of the Surtsey Eruption on the Nutrient Content of the Surrounding Seawater. J. Mar. Research, Vol. 24, Nr. 2.

Nematodes from Surtsey

By
BJÖRN SOHLENIUS
Zoological Institute, University of Stockholm

Nematodes have been obtained from two places on the Surtsey island. The animals were sent to the author on agar plates which had been inoculated on Surtsey by Dr. G. H. Schwabe on his visit to the island in July and August 1971. In agar plates, inoculated with material from the sediment in the bottom of a plastic van with fresh water, erected by Dr. B. Maguire and placed about 100 m from the eastern coast (place 349), two species of *Monhystera* were found. From a locality in the middle of the island (place 355), close to the place 237—242 (Behre and Schwabe, 1970), one species of *Acrobeloides* was isolated. This locality is described by Schwabe as: "Westliches Nebenkrater in Surtur I (auf dem direkten Wege von Glocke nach Neujahrskrater!), windglatte Feinasche, keine Moose, schwach feucht."

On October 11th, 1971, the cultures were examined and some animals were transferred to plates with soil agar and Nigon's agar as described in Sohlenius, 1968. The two *Monhystera* species did not survive in these cultures. The *Acrobeloides* species, however, grew readily on these two media and also on potato-dextrose agar (Difco), obviously utilizing the surface-dwelling bacterial flora as a food source. It produced dense populations on all three media and reduced all the visible bacterial growth somewhat before maximal population density occurred a few weeks after inoculation.

The dimensions and morphology of the *Acrobeloides* species resemble Anderson's (1968) description of *Acrobeloides nanus* (de Man, 1880) n. comb. Anderson, 1968. The species, earlier placed in the genus *Cephalobus* Bastian, 1865, according to Meyl (1960) is very common, almost cosmopolitan, and found all over middle Europe.

Acrobeloides nanus has been cultured together with bacteria on potato-dextrose agar by Anderson (1968). The effect of different micro-organisms as food sources for the closely related species *A. buetschlii* has been tested by Nicholas (1962). He found that this species could make use of several different bacterial species and he regards it as an unselective bacteria-feeder. It did not grow or reproduce when offered algae *(Chlorella)* or yeast *(Sacharomyces)*.

No males of *Acrobeloides nanus* have been found and according to Anderson's (1968) description of the development of the reproductive system, reproduction occurs by parthenogenesis.

The ability to survive desiccation was tested by letting the animals dry in slowly on agar-pieces and more rapidly on filter-papers. Thus animals kept for two months on dry soil agar at R.H. 30—35% and 20—22°C revived upon wetting. Within 12 hours several second stage larvae were active and after a few days the number of active larvae of several stages had increased pronouncedly. However, no adults or eggs resumed activity. The reactivated animals gave rise to dense populations when transferred to fresh agar plates. It was not possible to reactivate animals that had desiccated on filter-papers.

Acrobeloides nanus apparently has some adaptations and characteristics in common with other animals which have been found on Surtsey (Holmberg and Pejler 1972). Thus it can survive desiccation and is parthenogenetic, it certainly has a very wide distribution and occupies a low trophic level (unselective bacteria-feeder). Apparently this species is quite tolerant towards changing environmental conditions. This is indicated by the fact that besides on Surtsey it has been found in very different localities and also by its ability to grow and reproduce on so widely separated media as soil agar, Nigon's agar and potato-dextrose agar.

The *Monhystera* species have provisionally been identified as *M. dispar* Bastian, 1865 and *M. simplex* de Man, 1880. However, the identity of these species is uncertain as the taxonomy of *Monhystera* is in a poor state. No males of these species were found. It is probable that they occupy a low trophic level and they are certainly not predaceous.

Cultures with *Acrobeloides* are kept at the Zoological Department as well as preserved material of *Monhystera*.

References:

Anderson, R. V. 1968: Variation in taxonomic characters of a species of *Acrobeloides* (Cobb, 1924) Steiner and Buhrer, 1933. Can. J. Zool. 46:309–320.

Behre, K. und Schwabe, G. H. 1970: Auf Surtsey/Island im Sommer 1968 nachgewiesene nicht marine Algen. Schr. Naturw. Ver. Schlesw.-Holst. Sonderband. S. 31–100. Kiel, Nov. 1970.

Holmberg, O. and Pejler, B. 1972: On the terrestrial microfauna on Surtsey during the summer 1970. Surtsey Research Progress Report 6:69–72.

Meyl, A. H. 1960: Freilebende Nematoden, In: Die Tierwelt Mitteleuropas, Hrsg. Brohmer, Ehrmann, Ulmer. Leipzig, Quelle und Meyer, 164 S.

Nicholas, W. L. 1962: A study of a species of *Acrobeloides (Cephalobidae)* in laboratory culture. Nematologica 8:99-109.

Sohlenius, B. 1968: Influence of micro-organisms and temperature upon some rhabditid Nematodes. Pedobiologia 8:137–145.

GEOLOGY

The Sedimentary Xenoliths from Surtsey: Turbidites indicating Shelf Growth

By

TORBJÖRN ALEXANDERSSON

Department of Historical Geology, University of Uppsala, Uppsala, Sweden

ABSTRACT

Well-preserved sedimentary rocks from marine strata in the distal shelf occur as xenoliths in the Surtsey tephra. Fossilbearing xenoliths, to some extent affected by subaerial diagenesis, are previously known from Heimaey and Skammidalur. Marine biogenic carbonates (mainly aragonite and Mg-calcites) included in pyroclastic sediments are slowly affected by subaerial exposure; the changes differ from those in carbonate sedimentation areas. Aragonite shells are not dissolved, leaving molds; instead replacement without a void stage occurs. Depletion of Mg from Mg-calcites has not been observed. Upper Tertiary *Cyprina* shells are still aragonite.

The siliceous cement in the xenoliths is formed in two stages: (i) the grains are uniformly coated by a thin crystalline fringe, and (ii) the remaining pore space is filled by a metastable gel-type cement. Gradually the metastable phase is stabilized by crystallization processes.

According to C^{14} dating, sedimentary xenoliths from Surtsey were lithified within the last 6,000—11,000 years, probably in a submarine position. Equivalents of all intervals in a complete turbidity sequence occur in the material; also a massive-bedded deposit which is attributed to slow creep and small slides in submarine slopes. Present-day conditions around Surtsey probably lead to the formation of corresponding sediments.

The shelf in this extension of the Neovolcanic zone is broad and shows no influence of glaciation. It is concluded that an abundance of pyroclastic material from submarine volcanic eruptions in the area caused growth of the shelf by distal addition of fluxoturbidite sequences. Marine strata in the shelf are known to be about 700 m in thickness at Heimaey, and they occur inland at least as far as to Skammidalur.

INTRODUCTION

The Surtsey eruption penetrated the marginal part of the Icelandic shelf south of the Vestmann Islands in an area where the water depth is about 130 m. The locality is situated 33 km off the coast and about 8 km from the outer edge of the shelf, this defined as the 100 fathoms (185 m) depth contour.

Material from the rock sequence in the shelf became included in the ejacamenta during the explosive phases of the eruption, and that material is now found as xenoliths in the tephra. Any consolidation of the tephra on Surtsey has not yet occurred, and the volcanic cones are eroded by wind action, surface drainage, and slides, released by the under-cutting activity of waves. In July 1969 the slopes were lined by gullies and the edge of the crater Surtur II had been cut through in its western part. As the tephra is eroded xenolithic blocks become exposed, and usually they roll or slide down the slopes to a level surface, either in the crater or on the outside. Eventually most of them are covered again by eroded and re-deposited tephra.

Most of the xenoliths are lithified sediments and, according to the perfect preservation of carbonate organisms present in the rocks, they are virtually unaffected by the heat from the eruption. The material presents an opportunity to study well-preserved layers from a marginal shelf area, and the big size of the samples (up to 1 m diameter) is an advantage, especially in connection with the study of sedimentary structures and the distribution of organisms.

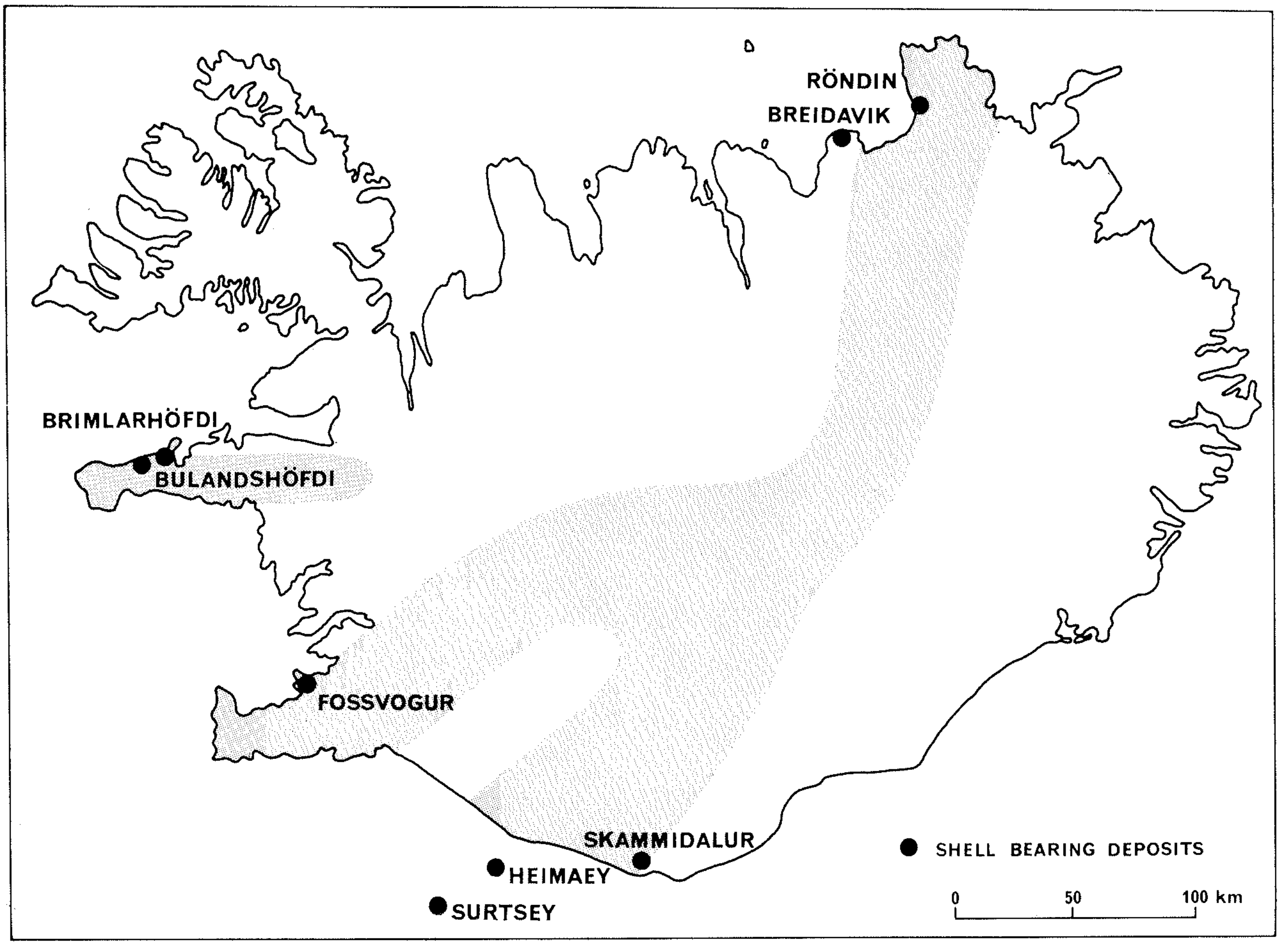


Fig. 1. Iceland with Neovolcanic areas and Pleistocene shell-bearing deposits (in part after ASKELSSON 1960). The shell-bearing deposits all lie within or near Neovolcanic areas.

SEDIMENTARY XENOLITHS AND SUBAERIAL DIAGENESIS

Xenoliths containing marine organisms are previously described from Skammidalur (ASKELSSON 1960, EINAR EINARSSON 1968) and from Heimaey (JAKOBSSON 1968). Both localities are situated in the zone of postglacial volcanism, the Neovolcanic zone, where also the Surtsey eruption took place, and the sediments obviously belong to the same sedimentary sequence. In this connection it is interesting to note that finds of Pleistocene shell-bearing deposits in Iceland generally lie within or close to Neovolcanic areas (map Fig. 1).

Skammidalur lies to the north of the coastal plain in the Mýrdalur district, 6 km from the coast and 75 km from Surtsey. Here a 200 m high scarp of *móberg* (literally "brown rock"; brownish palagonitized tuff and breccia) rises over the plain and the top of the móberg-formation is covered by glaciated lavas. Scattered in the móberg are boulders of sedimentary rocks with a lower Pleistocene marine fauna, i.a. the brachiopod *Rhynconella (Hemithyris) psittecea,* the pelecypods *Nucula tenuis, Mytilus edulis, Cyprina islandica, Venus gallina, Tellina obliqua* and the gastropods *Acteon noae, Nassa cf. prismatica* and *Turritella tricarinata* (ASKELSSON 1960).

JAKOBSSON (1968) reports sedimentary xenoliths in the consolidated tephra of the volcano Saefell on Heimaey, only 20 km from Surtsey. On basis of C^{14} analyses of peat he dates the Saefell eruption to about 5,000 years BP and the fauna in the sedimentary xenoliths is described as Recent. "It was possible to identify ten species of pelecypods, one gastropod and one foraminifer. All these species are found in the sea around Iceland today and at a depth similar to that found around the Vestmann Islands at the present time" (ibid. p. 115).

ASKELSSON (1960) characterizes the xenolithic sediments at Skammidalur as "consisting of rounded pebbles and water-worn sand-grains" but otherwise the sedimentary properties are not discussed.

The volcanic pile at Skammidalur is covered by glacially eroded lava, and is probably not

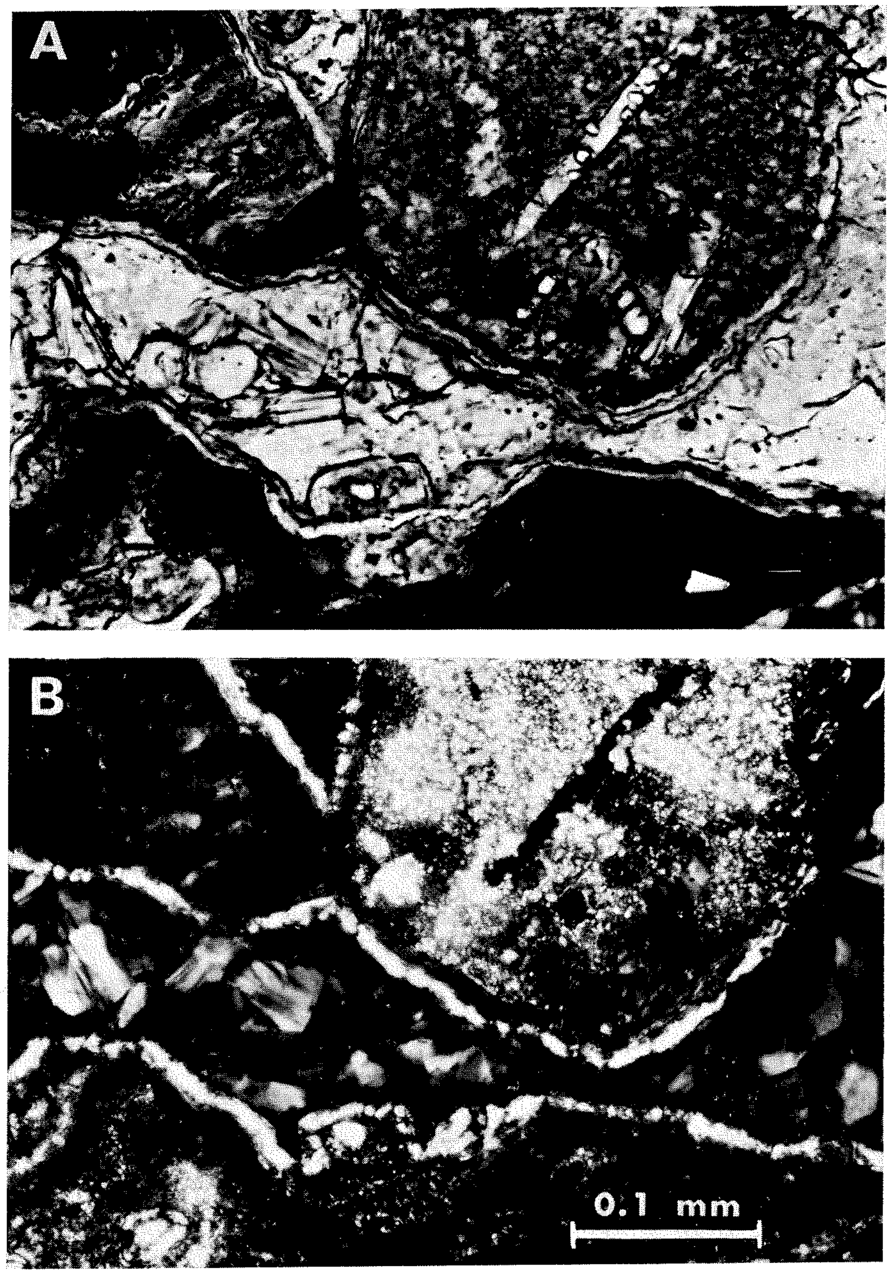


Fig 2. Sedimentary xenolith from Skammidalur. Thin section, A plain transmitted light, B cross-polarized. The cement consists of two components: (1) an epitaxial, isopachous fringe which is missing at grain contacts, and (2) a weakly birefringent siliceous substance, lacking a distinct crystalline fabric. Hand specimens are yellow-brown from subaerial alteration. (Specimen by courtesy of Einar H. Einarsson 1969.)

younger than late Glacial; the Saefell volcano on Heimaey is about 5,000 years old. Consequently, the sedimentary xenoliths found in these deposits have been exposed to subaerial diagenetic processes for a considerable time; their mineralogy and composition may have changed significantly, particularly where they were exposed to percolating groundwater. It is known that mineral assemblages which are stable or metastable under marine conditions may suffer rapid diagenetic changes upon exposure to fresh-water.

There occur in the sedimentary xenoliths three main components which as to origin represent different and specific environments; also conditions for subaerial alteration of these components are basically different. (1) *The pyroclastic grain component,* dominated by volcanic glass. This high-temperature product is not stable at earth-surface temperatures and pressures; the grains in the xenoliths are usually rounded by mechanical wear and they have probably also undergone chemical changes during transport and deposition. (2) *The cement* which is a diagenetic adjustment to post-depositional conditions. Theoretically, minerals formed under such conditions should be more resistant to weathering than volcanic glass. (3) *The biogenic material.* This consists mainly of calcareous parts of marine organisms; mostly mollusc shells and foraminifers and some serpulid worm tubes. The material represents processes controlled by metabolic activity, and diagenetic changes may start immediately after the death of the organism.

Fig. 3. Aragonite shells in coarse sediment from the *Mactra*-zone (Astian), Tjörnes. Polished surface. A black substance replaces the aragonite along growth lamellae in the shells. No intermediate void stage is apparent.

Pyroclastic component and cement

From the palagonitization typical for the *móberg* deposits it is evident that the pyroclastic material is very susceptible to diagenetic alteration (TYRRELL & PEACOCK 1926). The permeability of móberg is high and as a rule drainage is effectuated by groundwater flow (KJARTANSSON 1960). Ionic strength and pH of percolating water probably increases with depth by solution and hydrolysis of glass; so are, for instance, the tuffs on Oahu, Hawaii, progressively palagonitized at depth (HAY & IIJIMA 1968).

The processes that caused palagonitization of the móberg at Skammidalur and lithification of the tephra cone of Saefell also affected the xenoliths. This is apparent even from the colour of the material; the long-exposed xenoliths from Skammidalur are yellow-brown while the fresh sediments found on Surtsey are dark grey or black.

In thin sections the cement in the Skammidalur material corresponds to that described from Surtsey; a birefringent isopachous fringe surrounds the grains, while most of the pore space is filled by a weakly birefringent cement without any crystalline fabric (Fig. 2).

Biogenic material

Marine biogenic carbonates are dominated by the metastable minerals aragonite and Mg-calcites (VINOGRADOV 1953, LOWENSTAM 1954), and several authors have described the diagenetic course of events in areas of carbonate sedimentation (e.g. GAVISH & FRIEDMAN 1969). The first step is generally a loss of Mg from Mg-calcites without any textural changes; this is closely followed by dissolution of aragonite and interparticle cementation by calcite mosaic cement. During these stages partial re-

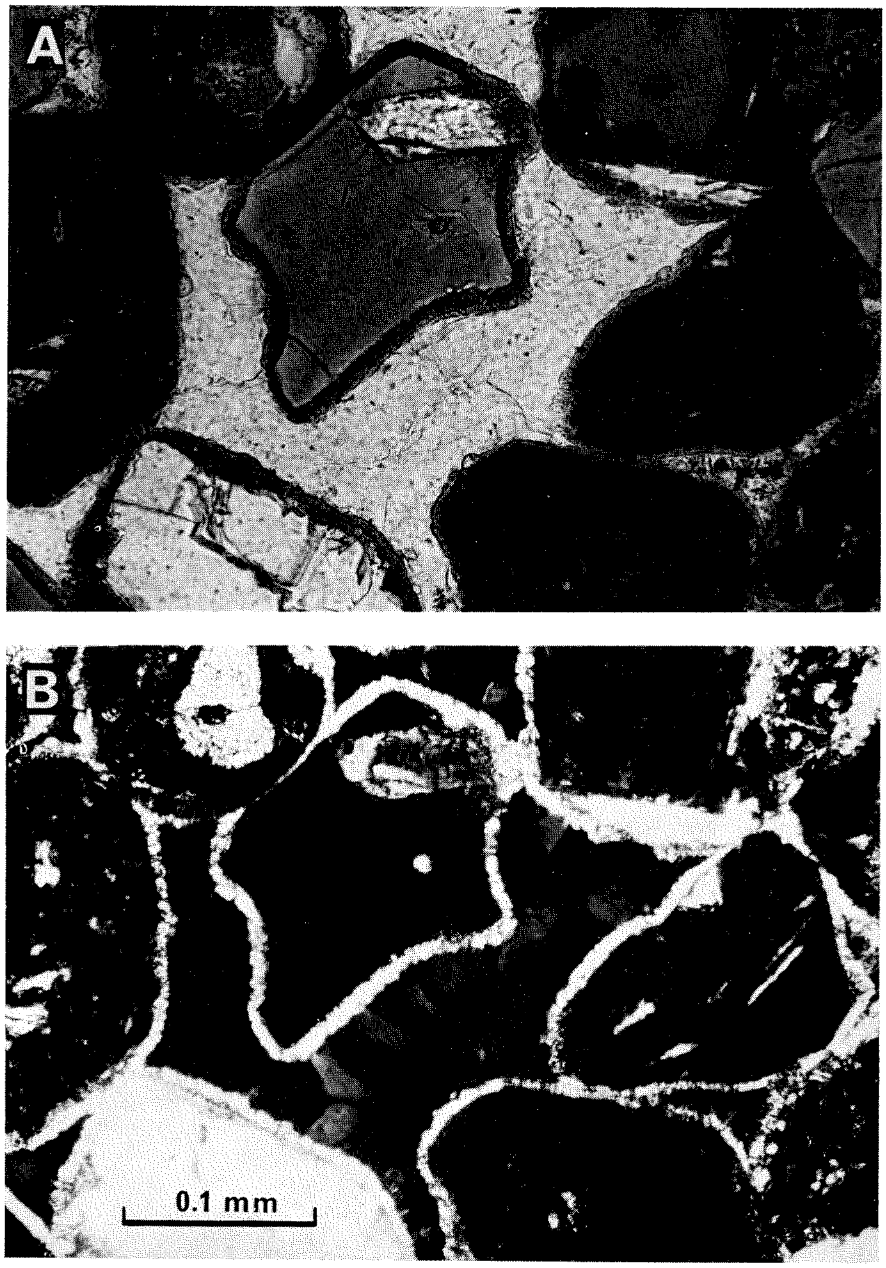


Fig 4. Sedimentary xenolith from Surtsey. Thin section, A plain transmitted light, B cross-polarized. Grains of different composition and mineralogy are all covered by a fringe of even thickness. A transparent siliceous cement which is almost isotropic, fills the remaining pore space (cf. Fig. 2).

placement of quartz and other silicate grains by carbonate also occurs.

It is less well-known what happens to shells and other biogenic carbonates which constitute only a minor component in a pyroclastic sediment. If any depletion of Mg from Mg-calcites occurs under such conditions is uncertain; HAY & IIJIMA (1968) report precipitation of authigenic calcite cement with 10–28 mole % $MgCO_3$ in the tuffs of Oahu, Hawaii, and simultaneous leaching of Mg from biogenic calcites seems improbable.

During diagenesis of carbonate sediments, dissolution of aragonite shells commonly leads to formation of molds which are subsequently infilled by a drusy calcite mosaic (WINLAND 1968). That process has not been observed in the present material, which includes samples of the shell-bearing pyroclastic deposits at Tjörnes (with Breidavík), Fossvogur, Skammidalur and Surtsey.

There occurs, however, a partial replacement of molluscan shells without any intermediate void stage. A black earthy substance which is insoluble in weak HCl, replaces the calcium carbonate; commonly this process proceeds along growth lamellae in the shells, and in sections these may appear striped in black and white (Fig. 3). In an advanced stage the complete shell is replaced by the black material, but this has been observed only in heavily altered xenoliths from Skammidalur.

Except for the replacement process, diagenetic

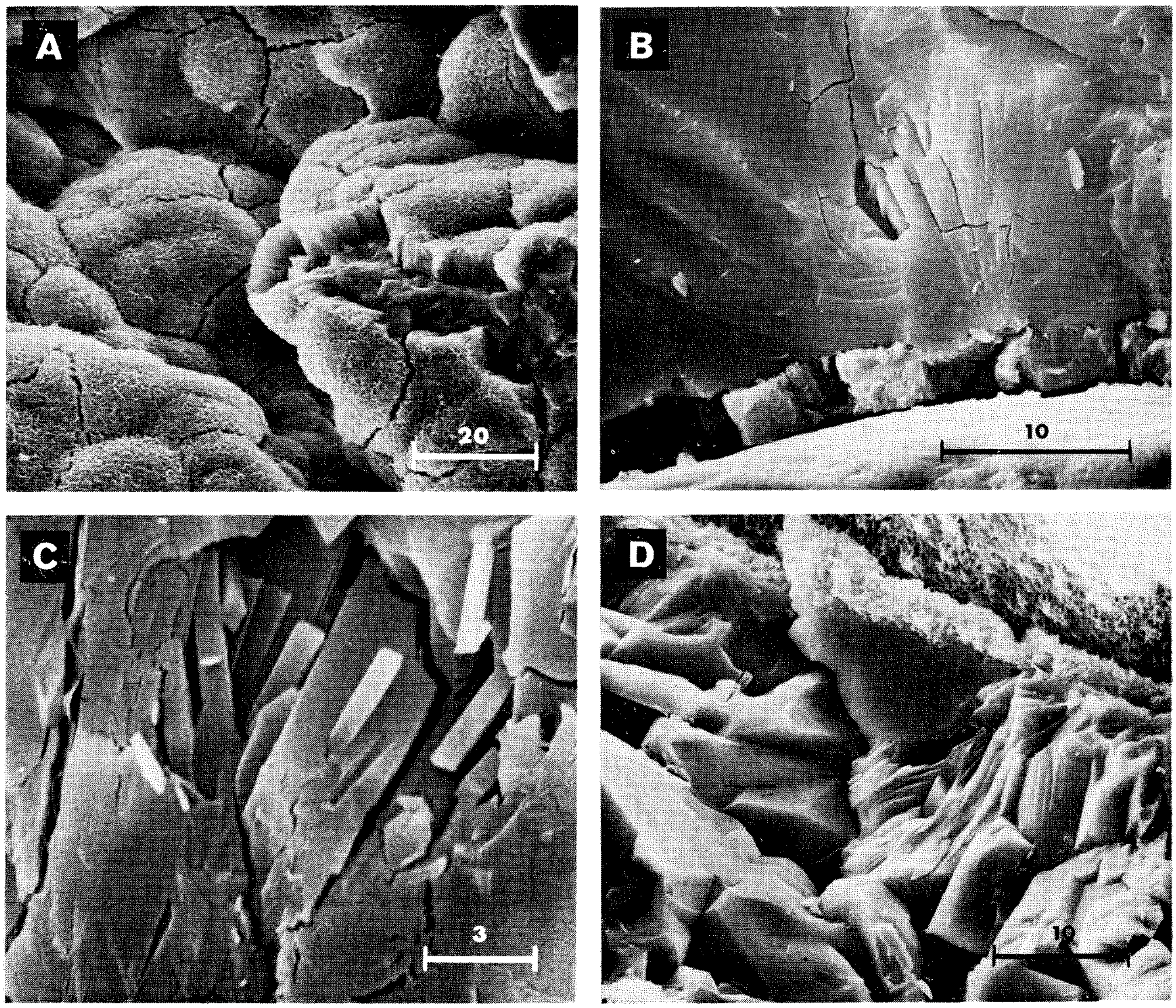


Fig. 5. Scanning electron micrographs of siliceous cement; fractured surfaces. A. Crystalline fringe cement in xenolith from Surtsey. All grains are coated by the uniform fringe; grain in right center is partly exposed by the fracture. The numerous shrinkage cracks are probably a drying effect. No gel-type cement is present in this deposit. Scale bar 20 microns. B. Xenolith from Surtsey. In order upwards: grain surface, crystalline fringe, gel-type cement. (Compare with D.) Scale bar 10 microns. C. Gel-type cement with shrinkage cracks. Small crystals, belonging to the earliest crystalline phase observed, are projecting out of the gel. Scale bar 3 microns. D. Xenolith from Skammidalur. In order downwards: grain surface, crystalline fringe, gel-type cement showing crystal faces. (Compare with B.) Scale bar 10 microns.

changes of biogenic carbonates under these conditions seem to be small; the oldest shells examined belong to the *Mactra*-zone (Astian) in the Tjörnes beds and, according to X-ray diffractometry, these are still pure aragonite.

SURTSEY SEDIMENTARY XENOLITHS

Composition and cementation

In a previous paper (ALEXANDERSSON 1970) it was reported that the sedimentary xenoliths from Surtsey contain *Cyprina islandica, Aporrhais pes pelecani, Pomatoceros* sp., *Dentalium* sp. and various foraminifers, and that the sediments consequently are marine. The calcareous parts of the organisms still retain their original mineralogy (aragonite and Mg-calcite) and have not been diagenetically altered; nor do they show any signs of leaching or dissolution. The same species occur in the seas around Iceland at the present time, and the opinion that the sediments are very young was supported by a radiocarbon dating of *Cyprina* shells which gave a preliminary age of 6,000—7,000 years BP.

The *Cyprina* shells were taken from two blocks and according to the final radiocarbon values these were not of the same age; one block (mainly "outer fraction") was approximately 11,000 years old while the other (mainly "inner fraction") was 6,200 years.*

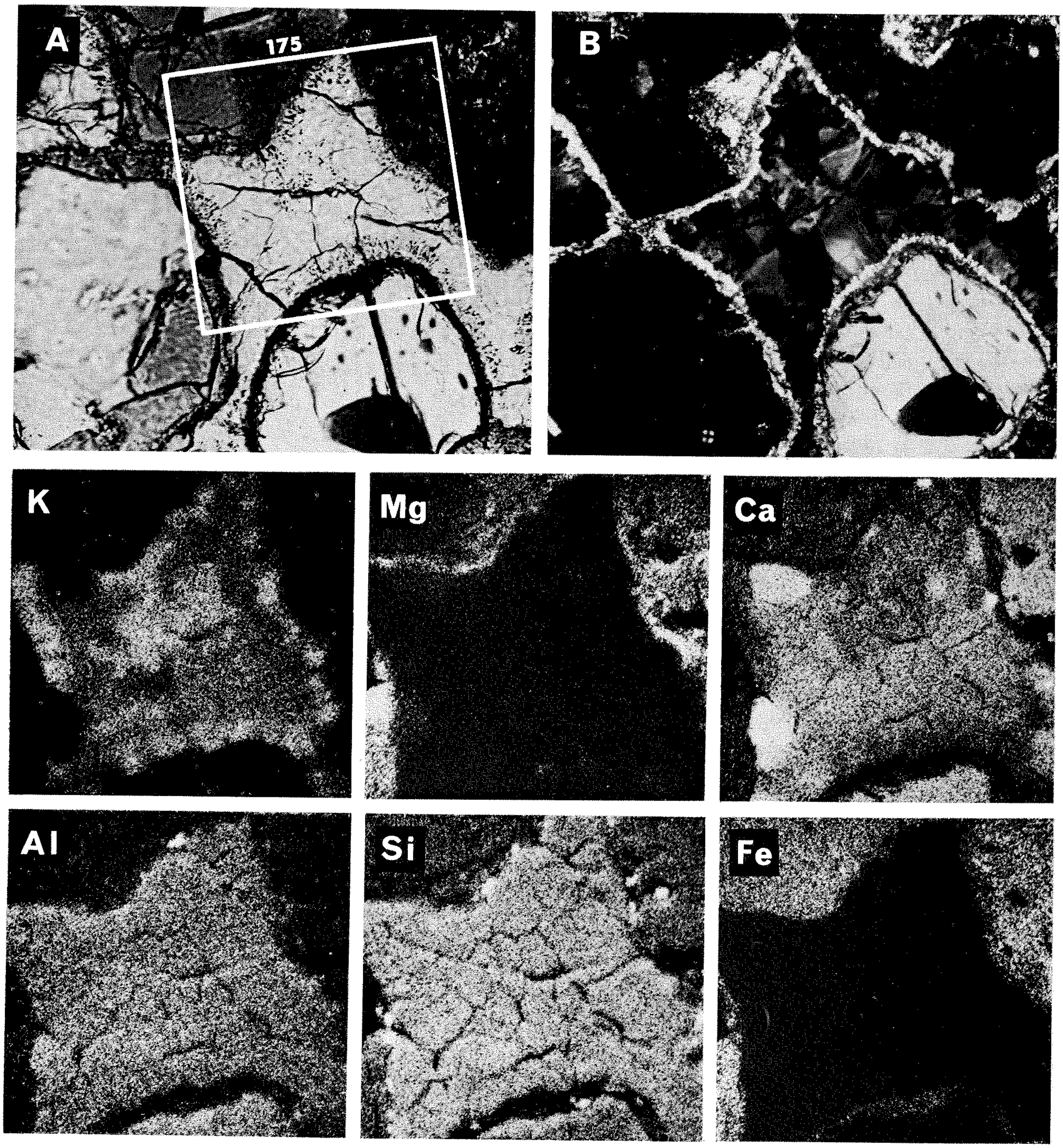


Fig. 6. Elemental composition of gel-type cement in sedimentary xenolith from Surtsey. A Thin section, plain transmitted light, B cross-polarized. Square in A scanned for distribution of elements in scanning electron microscope with X-ray spectrometer; side of square 175 microns. Note the high resolution in the scan pictures; even shrinkage cracks are resolved. The crystalline fringe was lost prior to scanning, during ultra-sound cleaning of the specimen. Only relative proportions are shown; the general intensity level depends mainly on the number of scans made.

---

* The C^{14} laboratory, Institute of Physics, Uppsala, Sweden:

	T½	
	5570	5730
U-2146 Surtsey 4+20, 6–68, inner $\delta C^{13} = +0.7$ ‰	6010 ± 190 B.P.	6180 ± 200 B.P.
U-2147 Surtsey 4+20, 6–68, outer $\delta C^{13} = -1.6$ ‰	$10570 \pm {}^{390}_{370}$ B.P.	$10870 \pm {}^{400}_{380}$ B.P.

The grain component of all sediments is of pyroclastic origin, but with regard to depositional conditions the rocks are of two types: (1) well-sorted massive-bedded sandstones, deposited under low water-energy conditions, and (2) conglomeratic deposits with subrounded pebbles in a sandy-silty matrix, often rippled and with graded bedding and indicating high-energy transport.

The siliceous cement usually consists of two principal components: (1) the crystalline *fringe,* which is a thin coating on the surfaces of the grains, and (2) the *gel-type cement,* a transparent, colourless substance which fills the remaining pore space (Fig. 4). The fringe encloses all grains, including shell fragments and foraminifers, but it is missing at grain contacts. It is formed by birefringent crystals, 4—10 microns in length, which are oriented normal to the coated grain surface (Figs. 4, 5 A—B). According to electron microprobe data the crystals contain Fe-Mg-Ca-Al-Si, but the precise composition, and their mineral form is as yet unknown. In some deposits the fringe is the only form of cement present (Fig. 5 A), and obviously it represents the first stage of cementation. Similar fringes of calcite crystals are described from marine lithification of carbonate sediments (LAND & GOREAU 1970, ALEXANDERSSON 1969). Alizarin red-S in acid solution, which is a stain specific for calcium carbonate (FRIEDMAN 1959, Warne 1962), does not stain anything except the biogenic carbonates in the present material, and it is clear that aragonite or calcite do not take part in the cementing processes.

The second component, the gel-type cement, has no distinct crystalline fabric, although it has a blocky appearance and very weak birefringence in polarized light. According to preliminary electron microprobe data, the average composition is 55—60% SiO_2, 25—30% Al_2O_3, and 10% Ca-Mg-K with substitution between K and Ca-Mg (Fig. 6). The sediment grains in contact have no direct influence on the composition of the cement.

The gel-type cement appears to be an initially amorphous and metastable substance, gradually stabilizing as it goes through several stages of crystallization. The earliest crystalline phase observed consists of minute laths, floating in the amorphous phase like halos around the grains (Fig. 6 A). Such laths are less than 1 micron in width, and 10—12 microns in length (Fig. 5 C); their composition and mineral form are unknown. However, they seem to represent an enrichment in K, and do not occur in the low-K phase (Fig. 6 A, and element distribution scans).

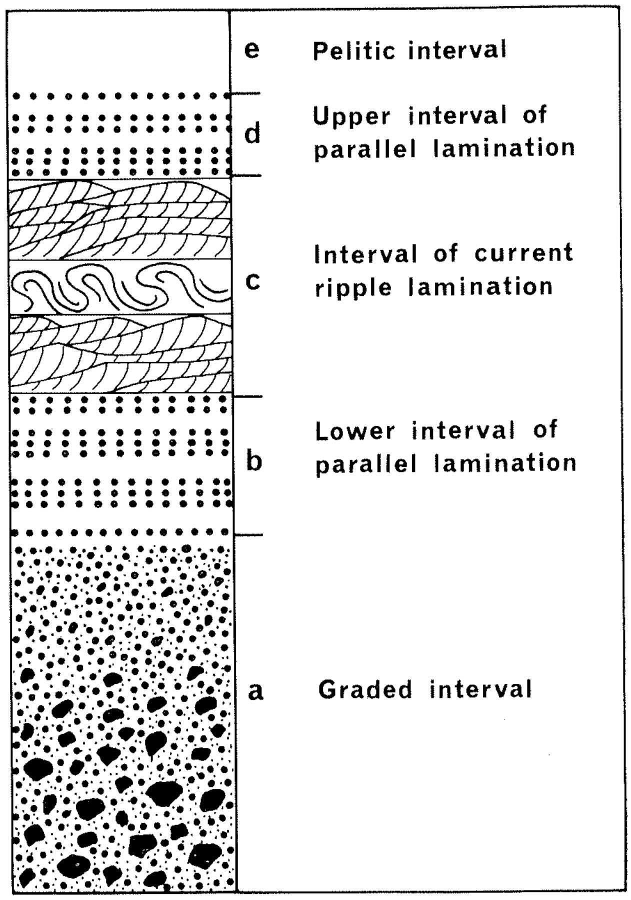


Fig. 7. Successive intervals in a complete turbidite sequence (BOUMA 1962).

Another ordering process affects the gel-type cement as a whole; in the fresh xenoliths from Surtsey this kind of cement typically shows conchoidal fractures without indications of a crystalline organization, while a corresponding fracture in the long-exposed xenoliths from Skammidalur reveals numerous crystal faces (Figs. 5 B and D).

The sedimentary rocks found as xenoliths on Surtsey were probably lithified in a submarine position (ALEXANDERSSON 1970). Submarine lithification of sediments seems to be unusual in the present seas (EWING et al. 1969); only recently has the process been recognized, and the mechanism is not very well understood.

In this connection the preliminary results from Site 115 of the JOIDES Deep Sea Drilling Project are particularly interesting (LAUGHTON et al. 1970). The site lies in 2.893 m of water, 480 km due south of the Vestmann Islands archipelago in the basin between the Reykjanes Ridge and the Rockall Plateau (position 58° 54.4′ N; 21° 7.0′ W); it was drilled on Leg 12, 14—16 July 1970. At 58 m sub-bottom the drill encountered

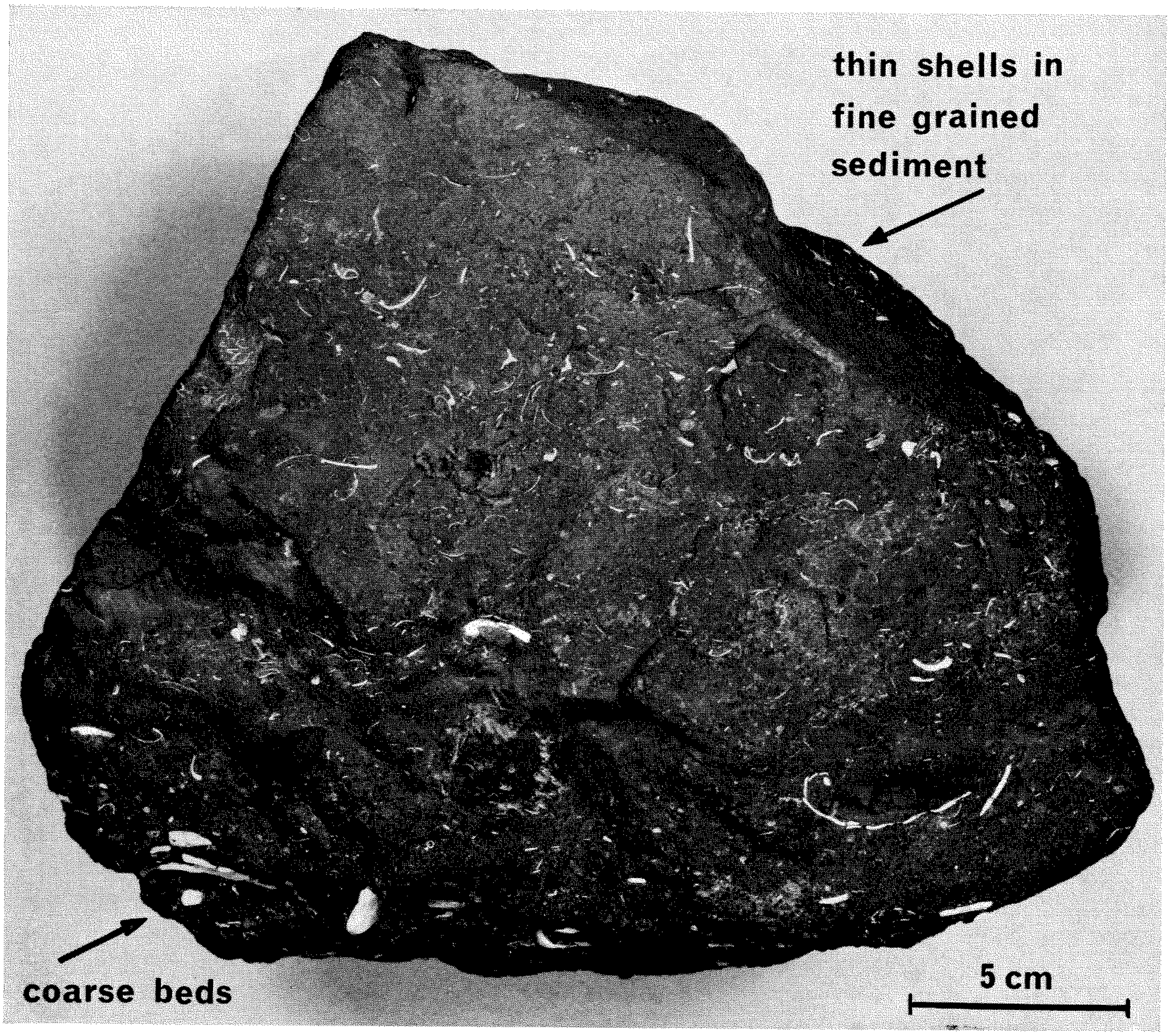


Fig. 8. Graded bedding in xenolithic boulder, Surtsey. Shells indicate pronounced decrease in transport energy; thick shells in lower coarse strata are broken while thin shells in fine-grained sediments are complete.

hard, graded, volcanogenic sandstones, interbedded with thin layers of unconsolidated sediments. The sandstone beds, some more than 1 m thick, persisted to a depth of at least 230 m sub-bottom where the bit was withdrawn. The firmly cemented beds are interpreted as turbidity current deposits of material from Iceland; they were obviously lithified in a submarine position.

Depositional features

A complete turbidite sequence consists of five intervals in a fixed, characteristic succession (BOUMA 1962). From the bottom to the top these intervals are: (a) graded interval, (b) lower interval of parallel lamination, (c) interval of current ripple lamination, (d) upper interval of parallel lamination, and (e) pelitic interval (Fig. 7).

Each of these five intervals is represented in the Surtsey sedimentary xenoliths, of which 80 —90 % is turbidite material (the high-energy sediments). Most common are graded deposits corresponding to interval (a). In these, subrounded pebbles of lava are scattered in a sandy-silty matrix which usually also contains shell fragments but rarely any complete shells. The biggest xenolithic boulders yet observed on the island (about 1 m diameter) belong to this kind of rock. In some cases the grading is distinct, and shells lie orientated on bedding planes; thick shells in coarse beds and thin shells in more fine-grained sediment (Fig. 8).

In other cases the grading is not distinct and sorting is poor. Shells in these beds are broken and many fragments are rounded and with a polished surface (Fig. 9). In the poorly graded

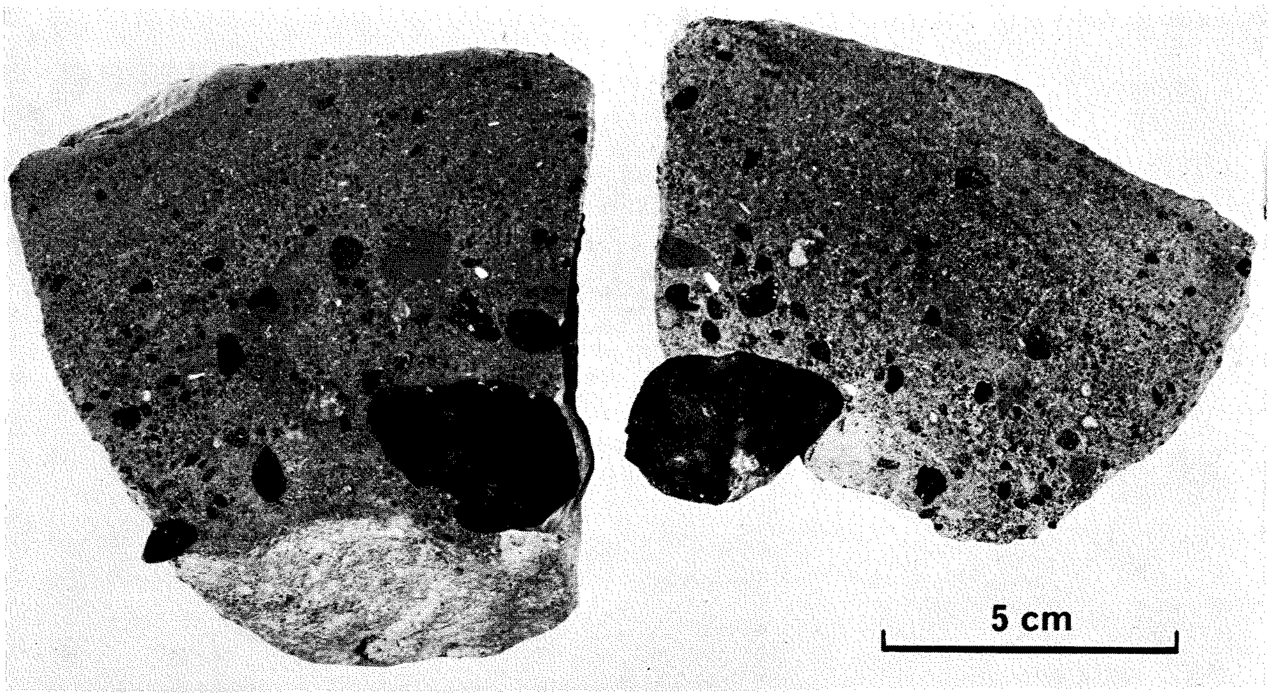


Fig. 9. Xenolith with poorly graded bedding, Surtsey. Cut and polished surfaces. In this kind of deposit (fluxoturbidite) no complete shells occur; fragments are often rounded and smooth.

material it is frequently seen how fragments from the same shell occur close to each other and yet separated by matrix and often pointing in different directions (Fig. 10). Such shells evidently went through the processes of transportation without damage and were broken in connection with the deposition. Shells become orientated in characteristic ways by wave and current action (NAGLE 1967); there is no current orientation of shells or fragments in the poorly graded layers.

It is probable that layers with indistinct graded bedding were deposited from a flow at an intermediate stage between slump and turbidity current, producing a *fluxoturbidite* according to DZULYNSKI et al. (1959). They assume this kind of transport to indicate: (1) a rich supply of material, and/or (2) a steep slope producing slides, and (3) a short distance to the source area and because of that little time for the sorting activity of turbidity currents to work.

The characteristics given by ASKELSSON (1960) for the xenoliths from Skammidalur are

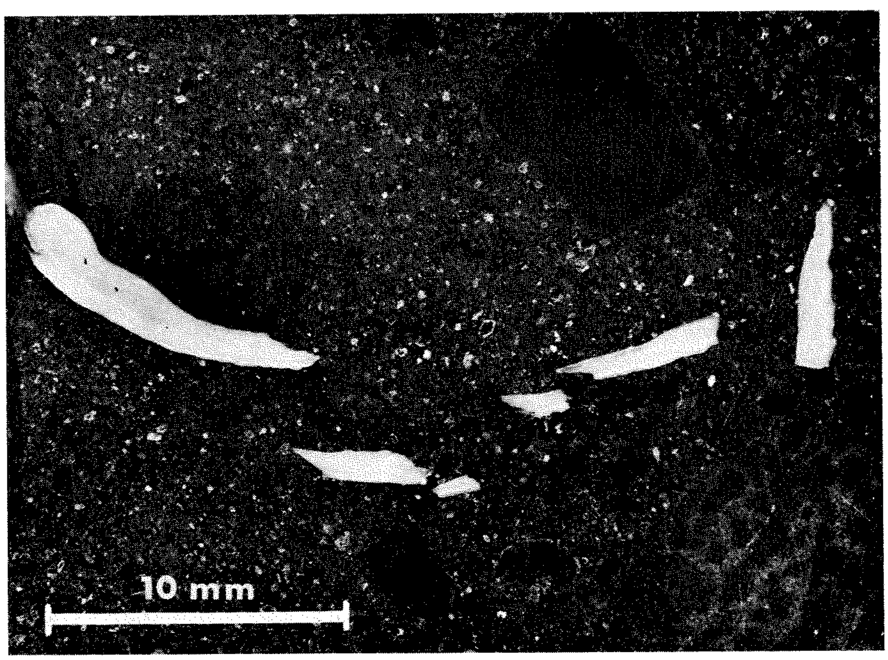


Fig. 10. Shell fragments in xenolith, Surtsey. Polished surface. All fragments are from the same shell; the surrounding material was viscous enough to break the shell just before the movement ceased.

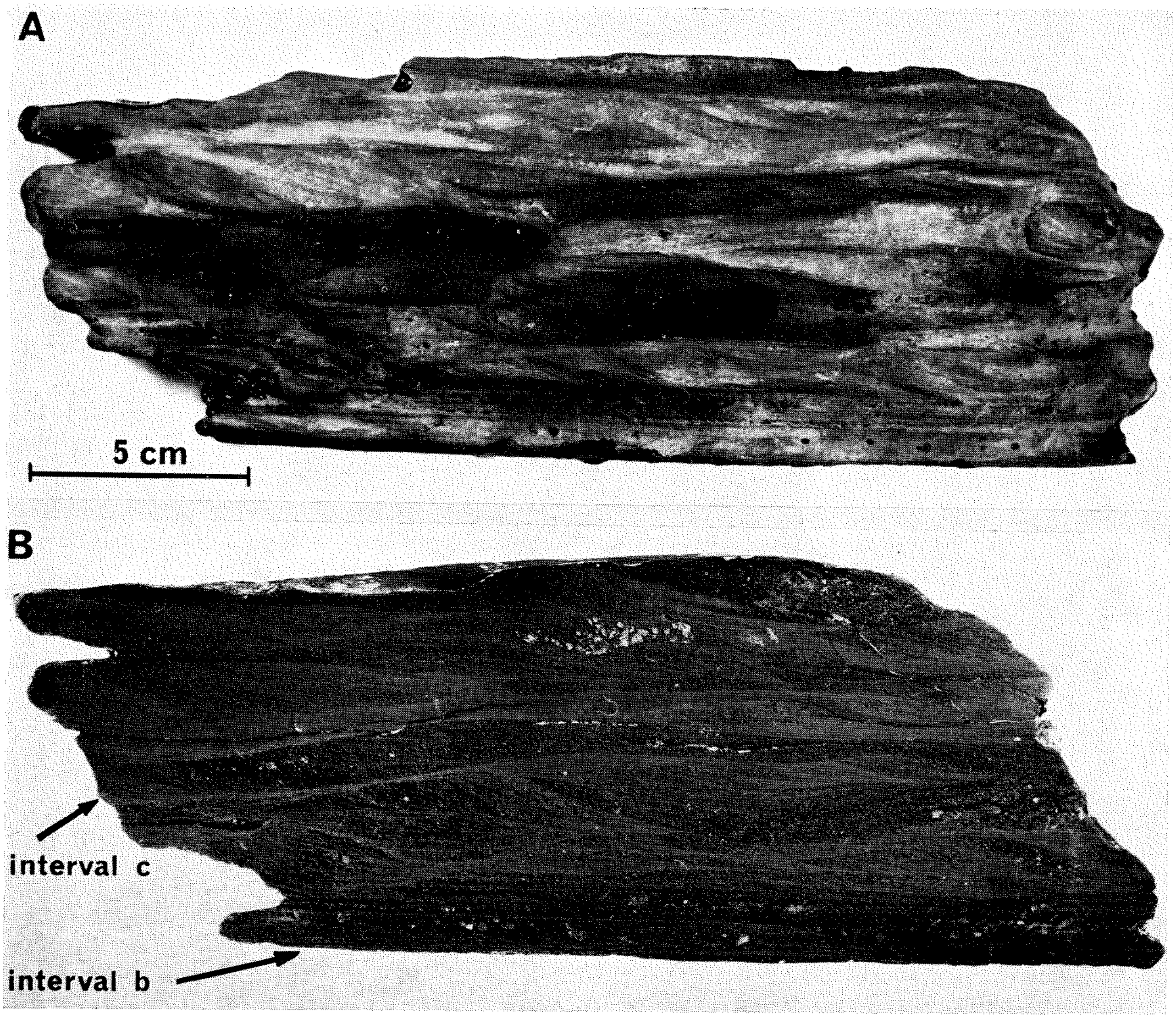


Fig. 11. Xenolith with lamination, Surtsey. A exterior with relief, B cut and polished surface. The deposit is loosely cemented and the block became sculptured by eolian corrasion in an exposed position on Surtur I. The layers correspond to interval b (lower parallel lamination) and c (current ripple lamination).

typical for material from the graded interval in a turbidity sequence.

Sediments with the characteristics of interval (b), lower parallel lamination, and (c), current ripple lamination, occur sparsely on Surtsey and most samples of that kind were found in the tephra cone of Surtur I. The majority of the ripples have a wave length of about 10 cm and a height of about 1 cm; thickness of the beds is usually less than 10 cm (Fig. 11). Convolute bedding is not well developed.

Upper interval of parallel lamination (d), and pelitic interval (e) also occur as thin beds, not thicker than about 10 cm. This indicates a scarcity of clay particles; conditions which are in general agreement with the geologic setting. Load casts and injection structures are common in this kind of material.

Foraminifers with a size of 0.3—0.4 mm occur frequently in horizons where the dominating size of solid particles is less than 0.1 mm. In the same layers the size of scoriaceous fragments with numerous vesiculae may exceed 1 mm (Fig. 12). These different particles have approximately the same hydrodynamic properties and may have settled simultaneously out of the tail of a turbidity current.

The xenolithic sediments which indicate high-energy transport all fit into the fluxoturbidite-turbidite pattern. Outside this pattern fall the well-sorted low-energy sediments, which must have formed under quite different conditions. The grains are rounded, the typical particle size is 0.2—0.3 mm and practically no silt or clay is present. Fossils are complete and unworn; frequently hollow shells are not even filled by sedi-

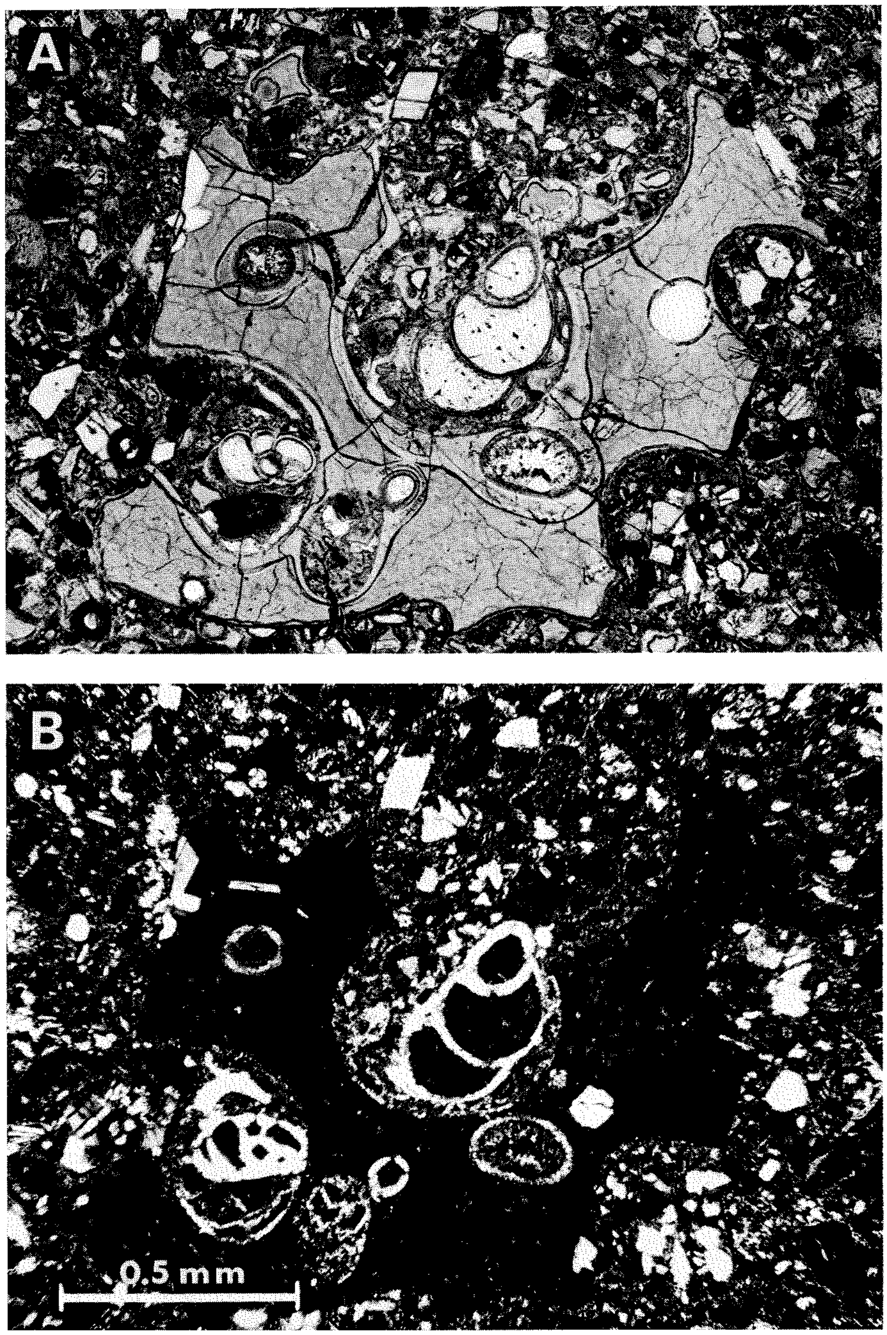


Fig. 12. Sedimentary xenolith from pelitic interval, Surtsey. Thin section, A plain transmitted light, B cross-polarized. The material is a silty pelite with no visible sedimentary structures (pelite = the fraction smaller than 50 μ). Foraminifers are common and occur here squeezed into the vesiculae of a scoriaceous fragment.

ment. The sediments are massive and show no signs of bedding or lamination. Shells are not orientated by wave or current action; they occur randomly distributed and possess widely different hydrodynamic properties. The major part of all identifiable organisms is found in deposits of this kind.

These massive sediments are assumed to represent slow creep of material and small slumps in over-steepened slopes; present-day conditions of that kind have been described from the northern end of Surtsey (NORRMAN 1970, ALEXANDERSSON 1970).

It is noteworthy that sediments indicating deposition under waveaction are not present in the Surtsey xenoliths.

SHELF MORPHOLOGY AND GEOLOGY

The southeastern part of the Icelandic shelf has a very characteristic morphology with a number of transverse sea-valleys running almost from the coast out to the shelf edge. On the submarine topography and the sediments of this area HARTSOCK (1960) reports: (1) Sand covers more than half the area out to the 100 fathoms depth contour. (2) Appreciable portions of the shelf are underlain by bedrock beneath the mantle of sediments. (3) The steep insular slope

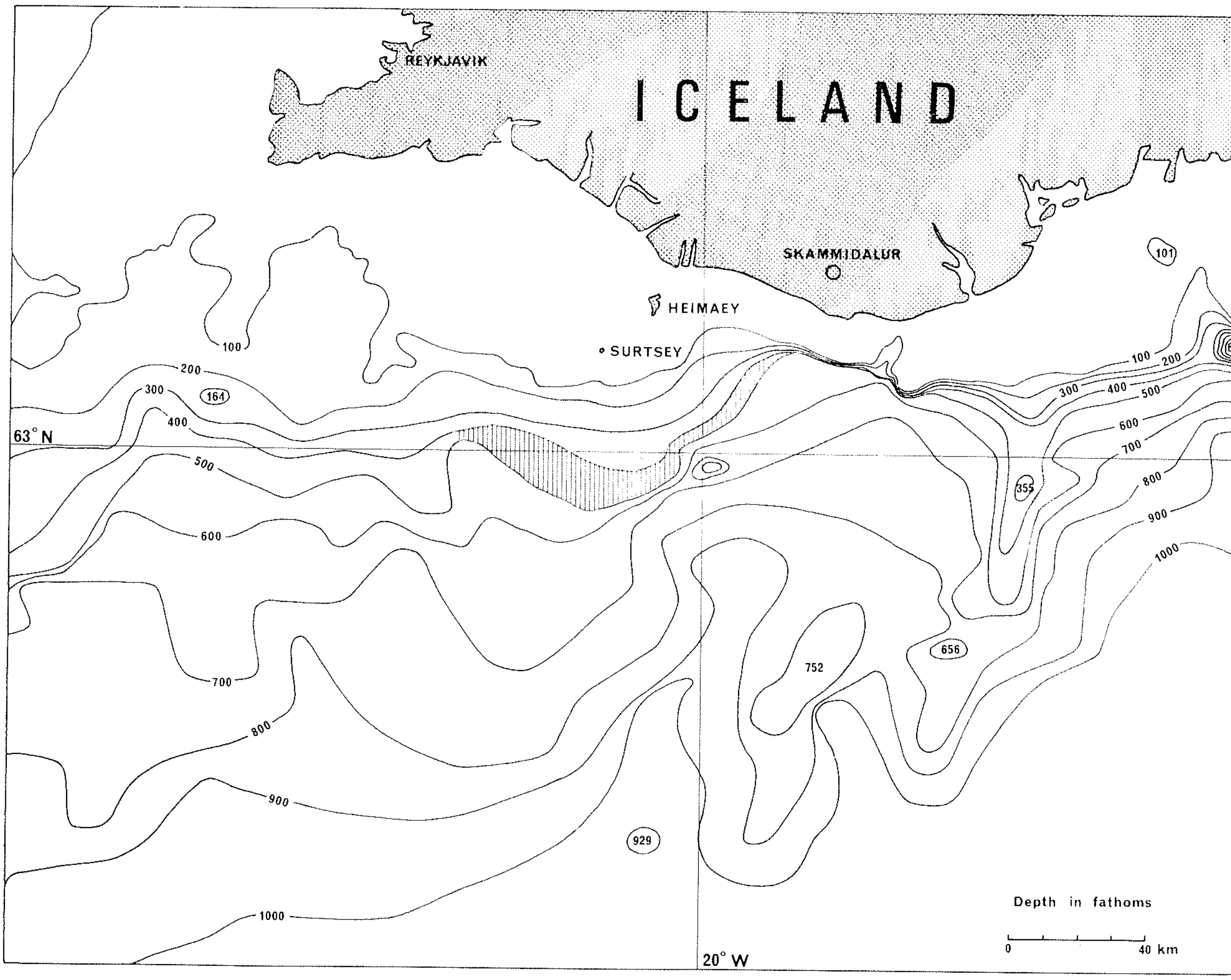


Fig. 13. Morphology and bathymetry of the Icelandic shelf from Skeidarár Djúp to Reykjanes Grunn. After British Admiralty charts 12, 246, 2733, 2968 and HARTSOCK (1960). Dark areas on Iceland = Neovolcanic zones. Vertical ruling in shelf slope = lower level of sedimentary sequence in Heimaey boring.

probably marks a zone of faulting with the southeastern side down-faulted. (4) The ultimate origin of the transverse sea-valleys is not clear; however, it is not improbable that Pleistocene glaciation of the shelf contributed to their present morphology.

Just east of the Vestmann Islands the shelf is only 12—15 km wide, the shelf edge is very distinct and the outer slope drops off rapidly, sloping about 17 degrees. Around the Vestmann Islands and further westward the shelf is 50—70 km wide and the morphology is quite different; there is no pattern of transverse sea-valleys, the outer edge is diffuse and the slope is one degree or less (Fig. 13). On the even shelf plateau numerous steep peaks rise above the level surface; some reach above sealevel and form the islands and skerries of the Vestmann Islands, but most of them occur in submarine positions. JAKOBSSON (1968) reports about 60 submarine peaks in the archipelago; all interpreted as remnants of submarine volcanoes and formed in the same way as Surtsey.

The area lies in the marine extension of the eastern branch of the Neovolcanic zone; an area of postglacial volcanism which traverses Iceland in SW—NE (Figs. 1 and 13). The number of subaerial postglacial volcanoes in Iceland is 150—200 and lava from these covers nearly 12,000 km^2; during the last two centuries eruptions have occurred on an average every fifth to sixth year (THORARINSSON 1960).

During the Surtsey volcanic event at least five main craters were formed (Jólnir, Surtsey I and II, Syrtlingur and Surtla), and it is probable that erosion of these will leave several peaks on the sea-floor. Evidently the number of former volcanoes in the Vestmann Island archipelago is not necessarily equal to the number of peaks on the shelf; even if this were the case the productivity of each eruption is difficult to estimate. However, there is little doubt that volcanism here has been very active and that the Surtsey eruption is the latest in a long series of similar events.

The submarine volcanism seems to be the main source of the material which is building out the shelf in this area. At moderate water depths even basaltic eruptions are explosive and most of the products should be clastic material (cf. the Surtsey event); great water depths or subaerial conditions are required for the production of lava.

The slopes of tephra cones which rise over the sea-floor are rapidly eroded. As seen from Jólnir, Syrtlingur and Surtla, volcanic cones which lack a protective cover of lava are levelled off down to 30—40 m water depth in just a few years (NORRMAN 1970). Submarine avalanches are common in the over-steepened slopes, and the environment should be favourable to the triggering of turbidity currents. Also all conditions postulated by DZULYNSKI et al. (1959) for the formation of fluxoturbidites are present.

All sediments in the xenoliths on Surtsey represent processes which might be expected in a marine environment where abundant pyroclastic material is supplied from not too distant sources. Of such processes, wave- and current-action, slow creep of material and submarine avalanches have been observed around Surtsey at the present time (NORRMAN 1970, ALEXANDERSSON 1970); turbidity currents, which appear to be the main transport mechanism, have not been observed in the field. Sediment cores from the present sea-floor in the area are not available, and to what extent structures indicating turbidity currents occur in the modern sediments is unknown.

The lack of xenolithic sediments which show wave- and current-influence is in agreement with the assumed depositional conditions. Those processes are active at shallow depths; for instance, they are the main agents behind the truncation of the Jólnir-Syrtlingur-Surtla cones. If the final deposition of sediments is due to turbidity currents, coarse material is brought to depths where the hydrodynamic forces are small relative to the grain size, and re-arrangement of material by waves or currents will hardly occur.

Data from a drilling for water on Heimaey in 1964 show that also the proximal part of the shelf to a considerable extent is formed by sediments (Fig. 14). The profile is described by PALMASON et al. (1965) and it is also discussed by TOMASSON (1967) and THORLEIFUR EINARSSON (1967).

The boring began 18 m above sea-level and penetrated 1565 m of rock. The sequence can be

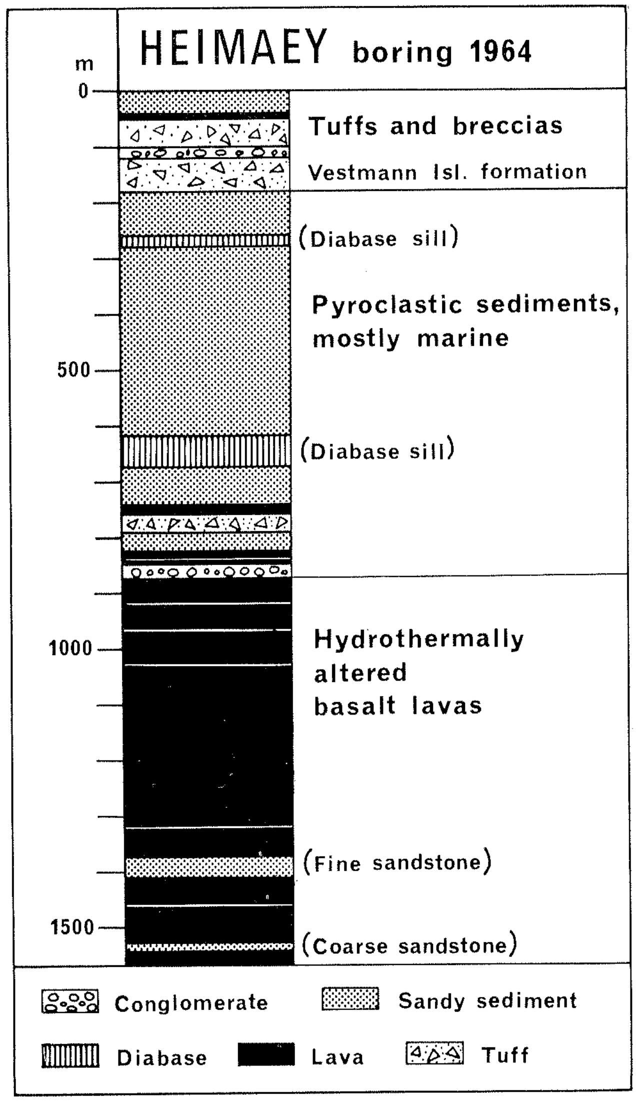


Fig. 14. Generalized profile of the Heimaey boring. After PALMASON et al. (1965) and TOMASSON (1967).

divided into three main units: (1) 0—177 m tuffs and breccias related to the formation of Heimaey (the Vestmann Islands Formation); (2) 177—870 m marine pyroclastic sediments, basal part probably lower Pleistocene; (3) 870—1565 m hydrothermally altered basalt lavas. There is probably a hiatus between the sediments and the lavas which are supposed to be "well down in the Tertiary" (THORLEIFUR EINARSSON 1967).

The low level of the basalt surface (approximately 850 m below sea-level) can be explained as due to a depression of the basalt plateau. This would mean an extreme development of the central Icelandic graben; a tectonic structure which elsewhere is supposed to be very shallow (e.g. TRAUSTI EINARSSON 1960 and 1967, THORLEIFUR EINARSSON 1967, RUTTEN & WENSINK 1960).

On the other hand, if the 500 fathoms (925 m) depth contour along the shelf to the east is extrapolated westwards, its continuation will lead almost exactly to Heimaey, and it is possible that the Heimaey boring is situated south of a buried extension of the shelf-bordering fault-line (Fig. 13). In that case the sedimentary sequence in the boring might represent a wedge of sediments, derived from sources to the west, and growing in an easterly direction on the down-faulted block, south of the shelf-bordering scarp.

The majority of available data can be interpreted both ways, but the presence of subsurface marine strata at Skammidalur 6 km inland indicates clearly that a sedimentation basin once existed in this part of the Neovolcanic zone. The surface deformation in the rift zones of Iceland includes both widening of the rifts (BODVARSSON & WALKER 1964, DECKER et al. 1971), and tectonic subsidence (TRYGGVASON 1968, 1970); the development of a basin of that kind is therefore a very probable process.

CONCLUSIONS

The sedimentological evidence supports the explanation that the Neovolcanic zone in the vicinity of the Vestmann Islands gradually subsided while being filled by pyroclastic sediments of a local origin. Marine strata occur inland at least as far as to Skammidalur, where they underlie the Pleistocene Móberg Formation (ASKELSSON 1960). At Heimaey the marine sequence has a thickness of about 700 m (PALMASON et al. 1965).

Due to a rich supply of material the insular shelf in the area grew by distal addition of sediments. Outside the Neovolcanic zone, 50 km to the east, no such growth occurred. The xenolithic sedimentary material from Surtsey indicates that transport to a great extent was gravity-controlled and lead to the formation of fluxoturbidite and turbidite sequences. Equivalents of all intervals in a complete turbidity sequence have been found in the xenoliths. Corresponding processes are probably active in the present-day environment and to some extent they have been observed around Surtsey.

Previously reported data (ALEXANDERSSON 1970) imply that lithification of the sediments may take place soon after deposition. Such sediments, which occur in the Surtsey xenoliths, differ from deposits affected by subaerial diagenesis, and lithification is supposed to take place in a submarine position. Compaction due to deep burial is not a primary cause.

ACKNOWLEDGEMENTS

I thank Prof. Sigurdur Thórarinsson and Dr. Thorleifur Einarsson for stimulating guidance in the field during the Scandinavian Geological Excursion 1969, and Dr. John O. Norrman for permanent friendly cooperation.

Field work on Surtsey in 1968 was financially supported by the Swedish National Science Research Council (NFR contract 2160–4 with Dr. Norrman), and in 1969 by the Surtsey Research Society. The help given by Steingrímur Hermannsson, Director of the Society, is gratefully acknowledged. Analyses and equipment were also financed via NFR contract 3045–1.

References:

Alexandersson E. T., 1969: Recent littoral and sublittoral high-Mg calcite lithification in the Mediterranean. Sedimentology, 12:47–61.

——, 1970: The sedimentary xenoliths from Surtsey: marine sediments lithified on the sea-floor. Surtsey Research Progress Report, V:83–89.

Askelsson, J., 1960: Pliocene and Pleistocene fossiliferous deposits. International Geological Congress, XXI Session; Guide to Excursion No. A 2, pp. 28–32.

Bodvarsson, G. & Walker, G. P. L., 1964: Crustal drift in Iceland. The Geophysical Journal of the Royal Astronomical Society 8:285–300.

Bouma, A. H., 1962: Sedimentology of some flysch deposits. Elsevier, Amsterdam.

Decker, R. W., Einarsson, P. & Mohr, P. A., 1971: Rifting in Iceland: new geodetic data. Science 173:530–533.

Dzulynski, S., Ksiazkiewicz, M. & Kuenen, Ph. H., 1959: Turbidites in flysch of the Polish Carpatian Mountains. Bulletin of the Geological Society of America 70:1089–1118.

Einarsson, Einar H., 1968: Steingervingar í Skammadalskömbum. Náttúrufraedingurinn 37:93–104.

Einarsson, Thorleifur, 1967: The extent of the Tertiary basalt formation and the structure of Iceland. In: Björnsson, S., (Editor): Iceland and mid-ocean ridges. Report of a Symposium. Reykjavík.

Einarsson, Trausti, 1960: The plateau basalt areas in Iceland. International Geological Congress, XXI Session; Guide to Excursion No. A 2, pp. 5–20.

——, 1967: Early history of the Scandic area and some chapters of the geology of Iceland. In: Björnsson, S., (Editor): Iceland and mid-ocean ridges. Report of Symposium. Reykjavík.

Ewing, M., Worzel, J. L., Beall, A. O., Berggren, W. A., Bukry, D., Burk, C. A., Fischer, A. G. & Pessagno, E. A., 1969: Shipboard site reports. Initial Reports of the Deep Sea Drilling Project I:3–320.

Friedman, G. M., 1959: Identification of carbonate minerals by staining methods. Journal of Sedimentary Petrology 29:87–97.

Gavish, E. & Friedman, G. M., 1969: Progressive diagenesis in Quaternary to Late Tertiary carbonate sediments: sequence and time scale. Journal of Sedimentary Petrology 39:980–1006.

Hartsock, J. K., 1960: Submarine topography and bottom sediments off the southeastern coast of Iceland. International Geological Congress, XXI Session; Part X:7—15.

Hay, R. L. & Iijima, A., 1968: Nature and origin of palagonite tuffs of the Honolulu Group in Oahu, Hawaii. The Geological Society of America, Memoir 116:331—376.

Jakobsson, S., 1968: The geology and petrography of the Vestmann Islands. Surtsey Research Progress Report IV:113—130.

Kjartansson, G., 1960: The Móberg Formation. International Geological Congress, XXI Session; Guide to Excursion No. A 2, pp. 21—28.

Land, L. S. & Goreau, T. F., 1970: Submarine lithification of Jamaican reefs. Journal of Sedimentary Petrology 40:457-462.

Laughton, A. S., Berggren, W. A., Benson, R., Davies, T. A., Franz, U., Musich, Lilian, Perch-Nielsen, Katharina, Ruffman, A., van Hinte, J. E. & Whitmarsh, R. B., 1970: Deep sea drilling project leg 12. Geotimes v. 15 n. 9:10—14.

Lowenstam, H. A., 1954: Factors affecting the aragonite: calcite ratios in carbonate secreting marine organisms. Journal of Geology 62:284—322.

Nagle, J. S., 1967: Wave and current orientation of shells. Journal of Sedimentary Petrology 37:1124—1138.

Norrman, J. O., 1970: Trends in postvolcanic development of Surtsey island. Surtsey Research Progress Report V:95—112.

Pálmason, G., Tómasson, J. & Jónsson, J., 1965: Djúpborun í Vestmannaeyjum. State Electricity Authority, Reykjavík. 43 pp. Mimeographed.

Rutten, M. G. & Wensink, H., 1960: Structure of the Central Graben of Iceland. International Geological Congress, XXI Session; Part XVIII:81—88.

Thorarinsson, S., 1960: The postglacial volcanism. International Geological Congress, XXI Session; Guide to Excursion No. A 2, pp. 33—45.

Tómasson, J., 1967: On the origin of sedimentary water beneath Vestmann Islands. Jökull 17:300—311.

Tryggvason, E., 1968: Measurement of surface deformation in Iceland by precision leveling. Journal of Geophysical Research 73:7039—7050.

—, 1970: Surface deformation and fault displacement associated with an earthquake swarm in Iceland. Journal of Geophysical Research 75:4407—4422.

Tyrrell, G. W. & Peacock, M. A., 1926: The petrology of Iceland. Transactions of the Royal Society of Edinburgh LV: 51—76.

Vinogradov, A. P., 1953: The elementary chemical composition of marine organisms. Sears Foundation for Marine Research, Memoir II, 647 pp.

Warne, S., 1962: A quick field or laboratory staining scheme for the differentiation of the major carbonate minerals. Journal of Sedimentary Petrology 32:29—38.

Winland, H. D., 1968: The role of high-Mg calcite in the preservation of micrite envelopes and textural features of aragonite sediments. Journal of Sedimentary Petrology 38: 1320—1325.

Use of Volcanoes for Determination of Direction of Littoral Drift

By

PER BRUUN and GÍSLI VIGGOSSON

The Technical University of Norway

ABSTRACT of paper presented at the 12th International Conference on Coastal Engineering in Washington, D.C. in Sept. 1970.

The title of this paper may sound like a joke. Correctly the title could be "Determination of Direction of Littoral Drift on the South Coast of Iceland by Geomorphological Approach". In order to check the results of such study based on the movements of river entrances and their geometry the use of an accelerometer buoy to be placed in offshore open waters for collection of wave data combined with the results of wave energy calculations based on meteorological data was discussed. Then SURTSEY suddenly emerged from approximately 400 ft depth in Nov. 1964 and its huge outpours of volcanic material built up an "offshore pole station", where the shoreline development during the period when the island had shores of loose material provided some information which supported the conclusion from the study on the mainland. Computation of wave energy input provided further information which supported the results of the other findings.

The littoral drift on the Icelandic south coast was investigated by means of topographic surveys and aerial photos including:

Survey by the Danish Geodetic Institute, 1906
Survey by the Danish Navy, ab. 1926
Aerial photography, 1945 (Icelandic Survey Dept.)
Aerial photography, 1960 (Icelandic Survey Dept.)
Aerial photography, 1960 U.S. Navy
Aerial photography, July 1963 (Icelandic Dept. of Lighthouses and Ports)
Aerial photography, Aug. 1963 (Icelandic Dept. of Lighthouses and Ports)

The results of studies of this material are depicted in Fig. 1, indicating that the predominant littoral drift at Hólsá is eastward, that the drift at the shore between Affall until west of Holtsós is neutral, that the drift from west of Jökulsá and up to Dyrhólaey probably is eastward although some minor outlets demonstrate westward direction which most likely is a seasonal phenomenon. Furthermore that the littoral drift just east of Dyrhólaey is westward. This is in agreement with findings by professor Trausti Einarsson published in article in Tímarit, Verkfrædingafélag Íslands (Proceedings of the Icelandic Engineering Association, No. 1—2, 1966, section IV "Radir foksandshóla og forsöguleg stada strandarinnar"). The result was compared to the development of shorelines at Surtsey as studied by Thórarinsson (Surtsey Research Progress Reports No. II and

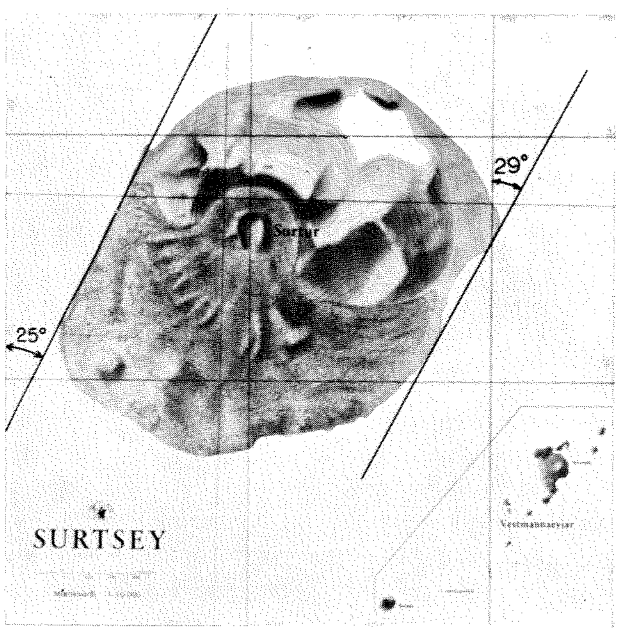


Fig. 2. Surtsey, October 23, 1964.

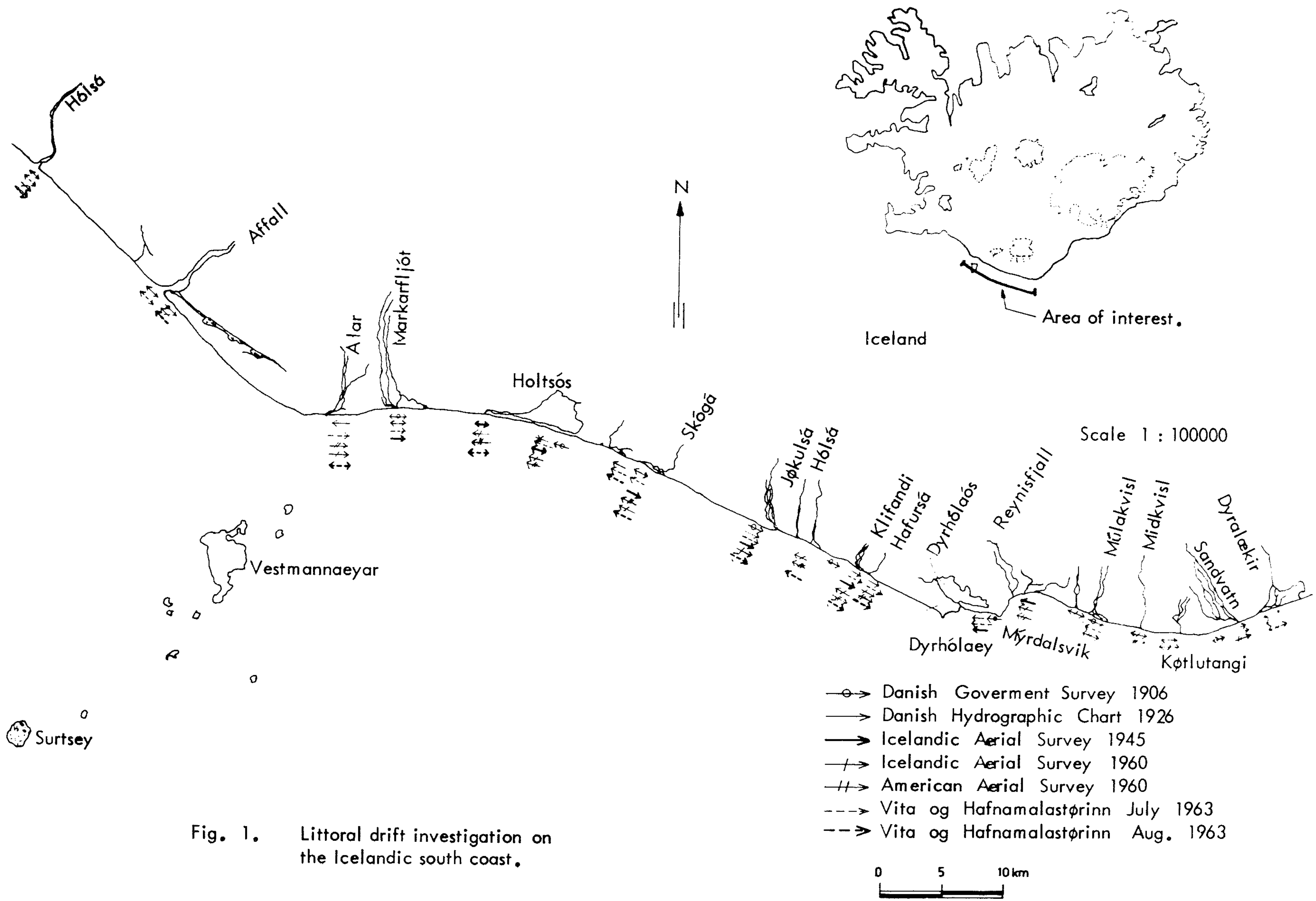


Fig. 1. Littoral drift investigation on the Icelandic south coast.

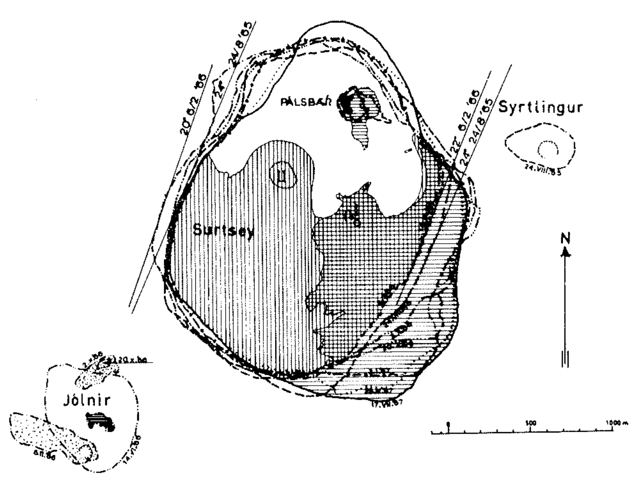


Fig. 3. Outlines of Surtsey during 1965 to 1967.

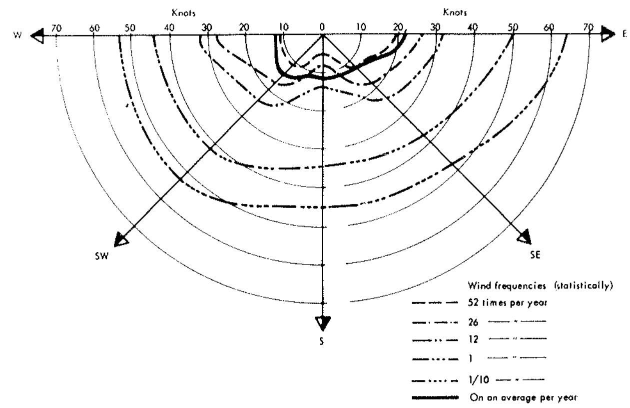


Fig. 4. Wind frequency diagram (offshore) the South Coast of Iceland.

III 1966 and 1967) and by Norrman (Surtsey Research Progress Report No. IV, 1968).

Figs. 2 and 3 show the development of shorelines at Surtsey during the period from 1964 to 1967 when coarse lava and pebbles normally were available in a narrow beach around the island for long-shore migration by wave action. During extreme storms the solid lava could become exposed, however, in certain sections of the shore. As it may be seen from the figures, the general trend of shorelines development was towards a rectangular shape with rounded cornes against SW. The island has two almost parallel sides running SW-NE and an accumulation area on the NE side which developed a lagoon between two beach ridges or barries growing out from SW, typical for an "angular foreland". The orientation of the two parallel sides is given in the figures. It may be seen that the average orientation of the two parallel sides in 1964 was 27 degrees E of N, which is identical with the orientation of the shoreline west of Dyrhólaey. Next an attempt was made to study the situation by evaluating the wave energy input on the shore in order to find the direction of shoreline with "neutral drift". No wave energy data were available however. The procedures were based on the socalled Los Angeles formula (ref. 1):

$$Q = \tfrac{1}{2}\, k_1 w\, e \sin 2\alpha_b$$

where Q = the total amount of sand moved in littoral drift past a given point per year by waves of given period and direction.

w = total work accomplished by all waves of a given period and direction in deep water during an average year.

e = wave energy coefficient at the breaker line for waves of a given period and direction. It is the ratio between the distance between orthogonals in deep water and at the shore line.

α_b = angle between wave crests at the breaker line and the shore line, or the angle between orthogonals and the normal to the shore line.

k_1 = factor depending on dimensional units and empirical relations. It varies with beach slope, grain size, and other variables.

The Los Angeles formula may be written as:

$$Q = 6.3 \cdot 10^8 \cdot k_1\, H^2_{1/3}\, T_{1/3} \cos\alpha_0 \sin\alpha_b$$

ft-lbs/year/ft of crest

where $H_{1/3}$ and $T_{1/3}$ are the significant wave height and period (average of highest one third of all waves and the corresponding average for wave periods). α_0 = deep water angle.

Wind conditions in Iceland are characterized by cyclones moving from SW giving rise to variable wind fields. The avarage duration of a cyclone moving from SW towards Iceland is 1 to 3 days. The predominant direction of wind wave propagation is towards NE. Because of the fact that no wave data were available it was necessary for a preliminary evaluation to use average wind conditions. Meteorological observations covering a period of 10 years were available. Wind data from three meteorological stations, located in the area between Vestmannaeyjar and Dyrhólaey, were statistically evaluated. Fig. 4 shows frequency diagram. The average wind speed ranged from 12 to 22.5 knots. Hindcasting was based on

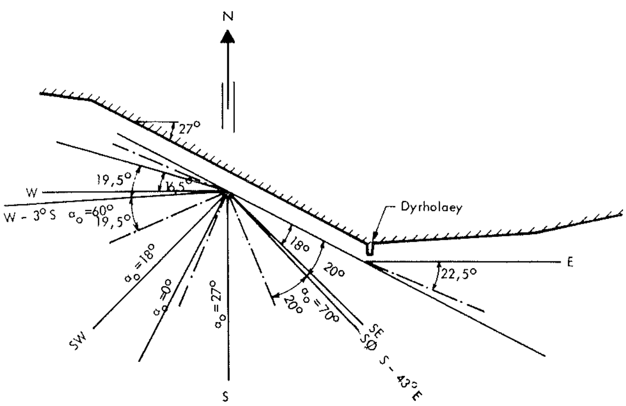


Fig. 5. The shore boundary conditions west of Dyrhólaey.

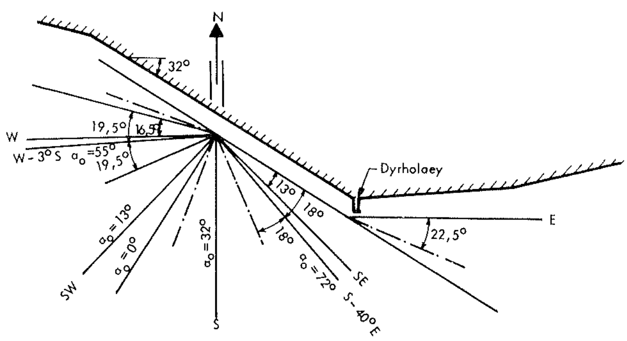


Fig. 6. The shore boundary conditions west of Dyrhólaey when the shore line is turned 5 degrees clockwise.

the SMB (Sverdrup-Munk-Bretschneider) method (ref. 2). The problem here, as usual, is to determine the fetch. A 22.5 knots wind generates a fully developed sea at a fetch of about 135 NM (nautical miles) and a duration of about 14 hours. The wave energy is a function of H^2 and T, and the SMB hindcasting diagrams indicate that wind speeds of 12 to 20 knots have no practical influence on the significant wave height, when the fetch increases from 100 NM to 250 NM. However there is an increase of one second in the significant wave period. For waves generated by the cyclones moving from SW, it is therefore realistic to select a fetch of 250 NM for W and SW. For the other directions a fetch of 135 NM was selected. This agrees with results of Danish investigations on wave action for the harbour of Vestmannaeyjar. The results of hindcasting of deep water energy is shown in Table 1—5 of the article in the Proceedings from the conference in the United States (published by the American Society of Civil Engineers in 1971).

Each wind direction represents a sector of 45 degrees. The actual shore boundary conditions including true shore orientation west of Dyrhólaey are shown in Fig. 5. In Fig. 6 the shoreline was turned 5 degrees clockwise in order to observe the possible influence of this on the drift direction computed on the basis of input of longshore wave energy. The input of energy from E was based on calculation of refraction and diffraction of waves. The results of this investigation was that the shore west of Dyrhólaey has a slight tendency to predominant eastward drift as also indicated by the two previously mentioned approaches. Turning the shoreline 5 degrees clockwise from the actual direction (Fig. 6) changed the resultant energy balance from eastward predominance causing westward drift of material.

It was noted that the wave steepness ratio H_0/L_0 (wave height over wave length in deep water) plays an important role for the longshore energy.

The calculations above still refers to the area just west of Dyrhólaey. Further westward the importance of E winds tends to decrease because of the shadow by the Dyrhólaey headland. This in turn would increase tendency to eastward drift. Assuming that this is correct, the shoreline should develop slightly convex (turn clockwise) up towards the Dyrhólaey apart from a small area influenced by leeside erosion just west of the Dyrhólapoint. This is actually the way shoreline configurations has developed. It is therefore evidenced that the orientation of shoreline of ab. 27 degrees N of W is close to the direction which causes neutral drift. The correct average direction may be a few degrees more as is in fact also indicated by the early development of shorelines at Surtsey.

Although none of the methods used are *exact* in the true sense of the word, the similarity of the results are noteworthy. It therefore appears that the development of shorelines of volcanoes popping up from the bottom of the sea, like Surtsey, may be used to determine the direction of littoral drift on nearby shores. As a good luck other methods are available, however. Volcanoes are not always on the spot when needed.

Referance:

Ref. (1) Bruun, P. (1954), 'Coast Stability', Danish Technical Press, 400 pp, section on 'Equilibrium Forms of Shorelines'.
Ref. (2) Kinsman B: "Wind Waves their generation and propagation on the ocean surface", Prentice Hall, Inc. Englewood Cliffs. N. J. 1965.

On the Consolidation and Palagonitization of the Tephra of the Surtsey Volcanic Island, Iceland

By

SVEINN P. JAKOBSSON

Mineralogical Museum, University of Copenhagen, Denmark

and

Dept. of Geology, Museum of Natural History, Reykjavík, Iceland

I. INTRODUCTION

About one third of the exposed part of Surtsey is made up of tephra, pyroclastics of alkali olivine-basaltic composition, formed in the phreatic eruptions in Surtsey during Nov. 14, 1963 – April 4, 1964. Since the formation of the tephra, samples have been taken in various localities every year (except 1965 and 1968) in order to find out when and how the expected process of consolidation and palagonitization of the tephra would start.

A thorough study of the petrology of the tephra-formation in Surtsey might give important answers to some of the problems of the chaotic subglacial "palagonite formation" of Iceland and to the question of formation of palagonite from basaltic glass in general.

Fig. 1. View of the north coast of Surtsey, looking to SE; August 5, 1970. In the foreground layered tephra with discordance in the layers in the middle of the sequence. To the left, finely bedded redeposit tephra. In the background, mud flows are conspicuous in the northern wall of the Surtur II crater. The field station can be seen at the left edge of the picture.

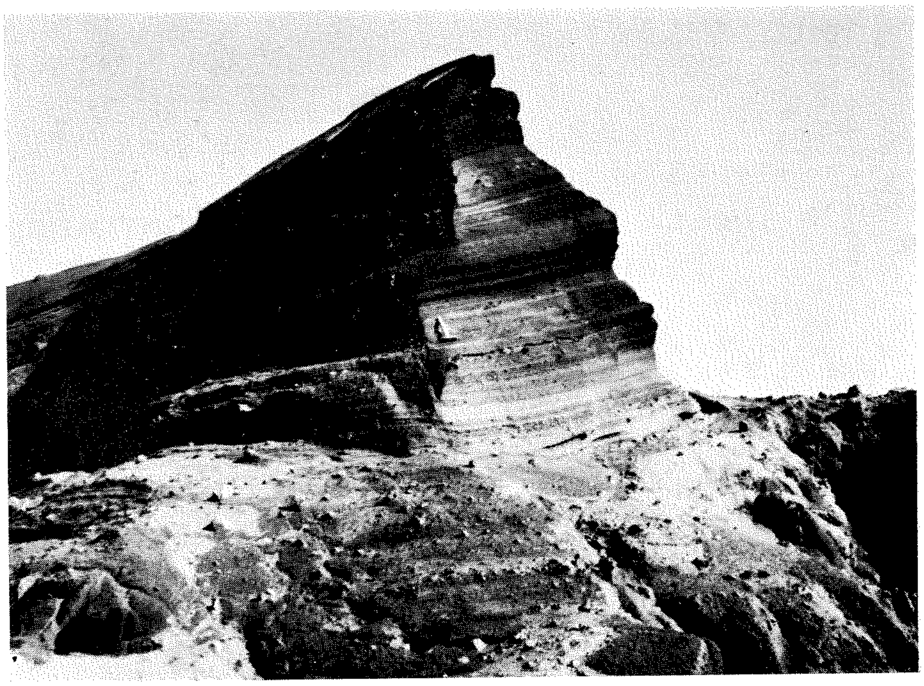


Fig. 2. Wind-eroded profile in the tephra, showing the characteristic layering. Top of eastern crater, August 5, 1970.

The first signs of consolidation in the tephra were seen in 1966, and in 1969 a marked consolidation process had begun, clearly connected to local heating of the tephra. It seems possible to define under what conditions these processes work.

II. GENERAL PROPERTIES OF THE TEPHRA

The tephra formed when the approx. 1150°—1160°C or hotter magma (Sigurgeirsson 1966) was quenched on contact with the seawater. The tephra felt still hot when it fell in the immediate surroundings of the crater, but it was only a matter of a relatively short time, possible only a few hours, before it had cooled down to air temperature. The quenching resulted in phreatic explosions and horseshoe-craters with a diameter of about 400 m and an height of 150—170 m above sealevel were formed. The tephra was deposited in finely-bedded layers (Fig. 1 and 2), each layer representing one shower. The crater and the tephra of the first phreatic phase (Nov. 14, 1963 — April 4, 1964) is for convenience called Surtur I *(S I)* and that of the second phreatic phase (Febr. 1 — April 4, 1964) Surtur II *(S II)*. For further details of the eruption history the reader is referred to the detailed descriptions of Thórarinsson et al. (1964) and Thórarinsson (1965, 1968).

Microscopic investigations on the tephra shortly after deposition (summer 1964) showed that 82—88% vol. was made up of unaltered and unpalagonitized basaltic glass (sideromelane), the rest being fragments of autogenic hyalobasalt and phenocrysts of olivine, plagioclase and Cr-spinel. The sideromelane is light-brown with a refractive index of $n = 1.605 \pm 0.002$. Dispersed in the tephra are grains of opaque glass (tachylyte); in contrast to the sideromelane, the tachylyte is magnetic. It is difficult to measure the density of the glass because of the great number of vesicles, but values around 2.70 g/cm^3 were repeatedly obtained. The tachylyte grains have similar density.

The grain size in five analysed samples varies, with more than 90% between 0.05—5 mm. The grain size curves have in most cases three maxima and are quite distinct from the curves of samples of tephra deposited in the seawater e.g. just north of Surtsey, which are rather wellsorted and have only one maximum. The content of olivine-phenocrysts varies greatly because of eolian differentiation. In the case of Jólnir (an island formed in 1966, which broke down the same year) the olivine content was found to decrease by 50% between two sites in contemporaneously formed tephra-layers at distances of 350 m and 1100 m from the crater.

III. CONSOLIDATION OF THE TEPHRA

The first signs of consolidation were seen in August 1966 in a few places, f.ex. at the top of the eastern mound. It was then possible to take a coherent sample, but it disintegrated when transported. Only the outermost 10—15 cm of the exposed tephra layers were consolidated. No

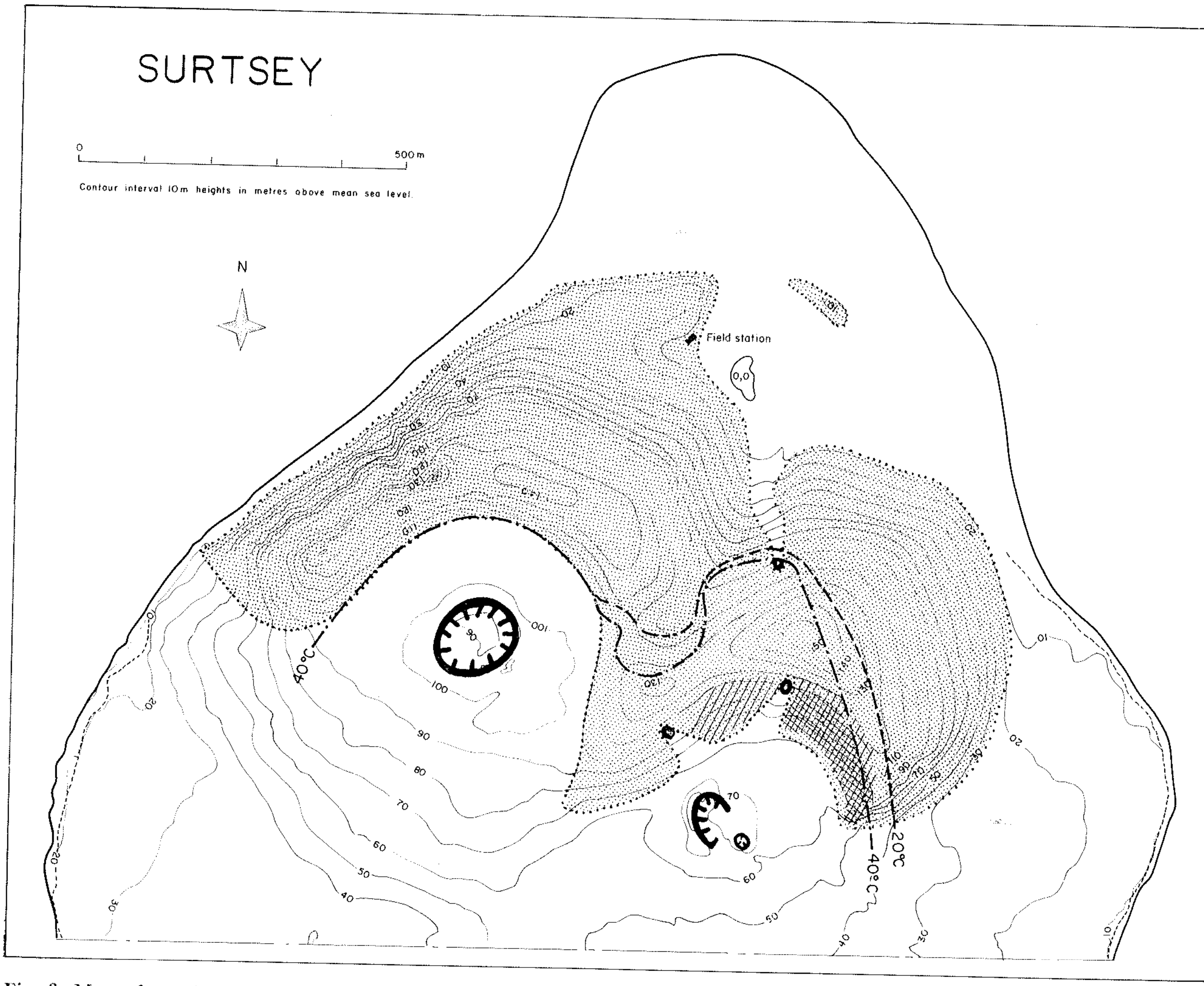


Fig. 3. Map of northern part of Surtsey (after air photographs of 6 July 1968,, Norrman 1970). The area of primary tephra is shaded, lava covers the whole southern part, but the costal plain to the north is mainly made up of sand and gravel. The extent of the thermal field within the tephra area as it was in August 1970 is indicated by the 20°C and 40°C isotherms (measured at the depth of 20 cm). The hatching shows the area of consolidated tephra, close hatching indicates hard tuff.

abnormal heat was observed in the layers. The exposures face SE, which is the main direction for precipitation and since this is also the sunny side, it is possible that the consolidation depends on the frequent oscillations in temperature and moisture on the surface. Microscopic examination of samples from one of the localities did not reveal any palagonitization and it was not possible to see (at 1000x) any cementing substance in the sample. These localities are since 1968 part of the thermal field which will be described below.

In Sept. 1969 a considerable area in the walls of the S I – tephra crater was already consolidated, probably as a result of the heating up of the tephra. In April 1968 Prof. Sigurdur Thórarinsson had discovered that a part of the older tephra crater (S I) was warm. In Sept. 1969 the present author visited the island and the thermal field was surveyed; temperatures between 48°–84°C

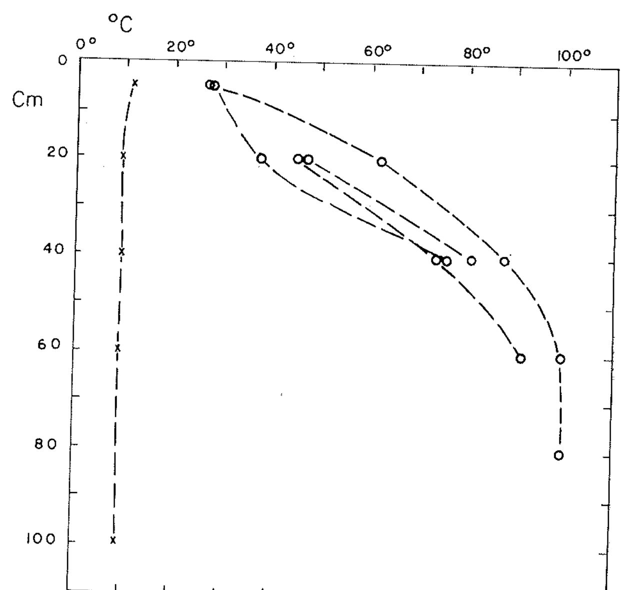


Fig. 4. Temperatures in five 40–100 cm deep holes in the Surtsey tephra (August 1970). Four of the holes are from the thermal field (circles) and one outside the field, at the field station (crosses).

were measured at approximately 5 cm depth in the hottest areas. The tephra in the thermal field was usually slightly wet and in some places steam escaped through the surface. In August 1970 the thermal field was mapped in detail, see Fig. 3, and it now seemed slightly larger than in 1967. At 20 cm depth the temperature was usually between 40°—60°C within the thermal field, but 10°C or lower outside the field. It was attempted to measure the temperature gradient by hammering an iron bar down (Fig. 4). Usually it was not possible to get farther down than about 40—60 cm within the thermal field as the tephra gradually became harder. As is evident from Fig. 4, the temperature gradient is very steep in the uppermost 40 cm of tephra, but as the temperature reaches 100°C the curve seems to flatten out. This could mean that 100°C is maximum temperature, at least near the surface. A small area in the northern part of the field was kept under observation for a few weeks in Aug.—Sept. 1970. At 20 cm depth the temperature was found to vary as much as 35°C at the same locality when measurements were repeated within a few days. Temperatures above 100°C were never obtained. From the above it could be suggested that the tephra is heated up by vapour at 100°C. It is very important to get this clear in order to ascertain at what temperatures the consolidation and palagonitization takes place at depth.

As is evident from Fig. 3 the thermal field surrounds the lave craters and it is therefore probable that the heating up is connected with heat flow through the feeder dykes of the lava craters. The lava crater S II (the westernmost one) was last in action in May 1965, whereas the craters S I ceased lava-effusion in June 1967. Heat flow through the craters continued however, in July 1968 temperatures around 500°C were measured in discharged gases in the S II lava crater, and as late as in Aug. 1970 temperatures as high as 400—500°C were obtained (Ae. Jóhannesson, pers. inf.). The temperatures of gases from the S I craters were somewhat lower.

As mentioned above it seems clear that the tephra, at least near the surface, is heated up by steam at 100°C. This steam can either be vapourized meteoric water which after precipitation seeps down to the 100°C level and then is vapourized, or it can be vapourized seawater which probably is present in the porous underground of Surtsey. In the small area which was kept under observation during Aug.—Sept. 1970 the temperature varied considerably, even from one day to the next. The volume of steam which escaped in this area seemed to increase with increasing temperature. It was not possible to see any connection between the precipitation as measured in this time interval at the weather station near the hut and the variations in the emanation of steam from the area. It could therefore be suggested that the steam is mainly seawater which becomes vapourized at sea level and then emanates through the tephra to become mixed with meteoric water near surface. This would mean that the palagonitization and the consolidation proceeds at 100°C below about ½ m depth with a more or less constant flow of water vapour at this temperature, and probably near atmospheric pressure. This could be ascertained with a shallow, say 50—100 m, borehole.

In Fig. 3 is shown the extent of the consolidated area on the surface in August 1970. A considerable area is semi-consolidated and here it is possible to take good coherent samples with a hammer, and about 7000 m^2 are made up of quite hard rock where a good hammer is needed when samples are taken. Elsewhere within the thermal field the tephra seemed hard and consolidated at 40—80 cm depht.

IV. PALAGONITIZATION

Within the consolidated area which was observed in Sept. 1969 a few small rust-brown patches were found in the tephra, especially where the vapour emanation was strong. The glass grains were distinctly coloured, but usually only on the under side of the grains which turned towards the vapour stream. Under the microscope the outermost 0.05—0.10 mm of the sideromelane grains were found to be altered to red-brown "gelpalagonite" (Peacock 1926, Noe-Nygaard 1940), i.e. isotropous and apparently homogenous palagonite. In many cases the palagonite is concentrically banded, possibly due to fluctuations in temperature and amount of steam. The refractive index is $n = 1.665 \pm 0.002$, i.e. considerably higher than before alteration, in contrast to the palagonite in the tuffs of the older Westman Islands, whose refractive index is lower, usually about 1.56—1.58. Samples from the same area taken in Nov. 1969 and in Aug. 1970 showed a similar degree of alteration (Fig. 5). In these red-brown patches in the tephra, approx. 1—3% vol. of the rock was palagonized. It does not appear that the palagonite is the actual cementing substance. It was possible to take consolidated samples before any palagonitization was visible in the micro-

Fig. 5. The incipient palagonitization of a sideromelane grain in tuff taken in Nov. 1969, about 0.7 mm of the grain is seen. In the glass are a few microlites of plagioclase and olivine.

scope. The cementing substance, if any, can possibly be identified by electron mircoscopy.

The sideromelane and its first alteration product, the red-brown gelpalagonite were analysed in one grain from the sample taken in Sept. 1969 (TABLE 1, I and II), each analysis is the average

TABLE 1

wt %	I	II	III	IV	V	VI
SiO_2	: 46.5	23.6	36.6	146.6	110.0	75.0
TiO_2	: 2.5	4.2	6.5	7.9	1.4	17.7
Al_2O_3	: 16.0	5.2	8.1	50.4	42,3	83.9
*Fe_2O_3	: 12.4	25.2	39.1	39.1	0	0
MgO	: 4.8	3.9	6.0	15.1	9.1	60.3
CaO	: 10.8	2.3	3.6	34.1	30.5	89.4
Na_2O	: 3.3	0.05	0.08	10.4	10.32	99.2
K_2O	: 0.6	0.02	0.03	1.9	1.87	98.4
SUM:	96.9	64.5	100.0	305.5	205.5	

* Total Fe as Fe_2O_3.
I: Electron — microprobe analysis of sideromelane in the grain shown in Fig. 6. II: Do — of palagonite rim. III: Palagonite analysis calculated waterfree. IV: Sideromelane values multiplied with 3.153. V: Difference between IV and III, loss of leached components. VI: Loss in % of original amount.

of 3—4 single counts. The analyses were made on the ARL electron microprobe, using as standard a basaltic glass from Hawaii, kindly provided by R. L. Hay. The palagonite analysis was difficult to make and should only be considered as semi-quantitative. The sum of the analysis is only 64.5% which is suspiciously low, it is, however, not impossible that water amounts to 35%. The sideromelane, which represents the average composition of the magma minus phenocrysts, proved to be very homogenous, whereas the palagonite rim was rather heterogenous. The process of palagonitization appears to be isovolumetric.

As seen from these preliminary analyses all components are depleted in terms of weight per cent, except Fe and Ti and water. Fig. 6 shows how e.g. Ca and Na are lost with palagonitization in a single sideromelane grain. Microlites are unaffected. It would here be interesting to calculate the change in concentration per volume, but as the specific gravity of the palagonite is not yet known this is not possible.

Approximate values of the relative amounts of leached components can, however, be obtained by assuming that the amount of total iron is constant during palagonitization, following the procedure of Hoppe (1940, p. 487). Probably all the iron in the palagonite is found as Fe^{3+} which is rather insoluble, cf. the experiments of Hoppe (op. cit.). On this assumption the values of the sideromelane analysis in Table 1 were multiplied with 3.153 as the iron content of the palagonite is higher by that factor. From the values obtained in this way (IV) are then subtracted the values of the waterfree palagonite analysis (III) and the difference gives the relative amount of each component that has been leached out.

It then appears (Table 1, VI) that the following components are lost in order of relative amounts: Na_2O, K_2O, CaO, Al_2O_3, SiO_2, MgO and TiO_2. Instead, water enters the palagonite, and as mentioned before, probably all the iron becomes oxidized to give the palagonite a rust-brown colour. The above mentioned elements are the same as Hoppe (op. cit.) found by experiments to be leached out of sideromelane in varying amounts at various pH conditions. pH has yet to be measured in the condensate of the steam which flows through the tephra in Surtsey. Microprobe analyses by Hay & Iijima (1968) of sideromelane and palagonite from Hawaii showed that three quarters or more of the K_2O, Na_2O and CaO, half of the Al_2O_3 and about one third of the SiO_2 were lost in the process of palagonitization.

In palagonite tuffs of the older Westman Islands, e.g. in Sæfjall, Ellidaey and Bjarnarey which are 5000—6000 years old (Jakobsson 1968), zeolites and calcite have been precipitated as the result of palagonitization. Of the zeolites, analcime, phillipsite, chabazite and natrolite have been identified. In Surtsey opal along with traces of thenardite (?) was discovered on the surface already in Nov. 1969 in areas with strong emanation of steam. The last-named mineral is possibly formed because of a high content of precipitated seasalts in the tephra. Sigvaldason (1965) has reported encrustations of halite and aphthitalite on lava and tephra in Surtsey. In Aug. 1970 opal was clearly much more abundant. At the time of writing (May 1974) the first zeolite has just been discovered in a sample taken in Surtsey on 28th April 1971; the zeolite is probably chabazite. Both the opal and the zeolite is believed to be the product of palagonitization as these secondary minerals have only been found where palagonitization has occurred and are made up of the principal components leached out of the sideromelane.

Outside the thermal field no consolidation or palagonitization has yet been discovered. This of course does not mean that it is ruled out that these processes can proceed under these circumstances, only that they are slowed down because of lower (atmospheric) temperatures and less moisture.

The ions which are found in solution on the surface of the glass grains as a result of palagonitization will be available to organisms which eventually colonize on the surface of the tephra. In this connection it is of interest to consider that the rock constituents of Icelandic soil are in most parts of the country by 80—95% made

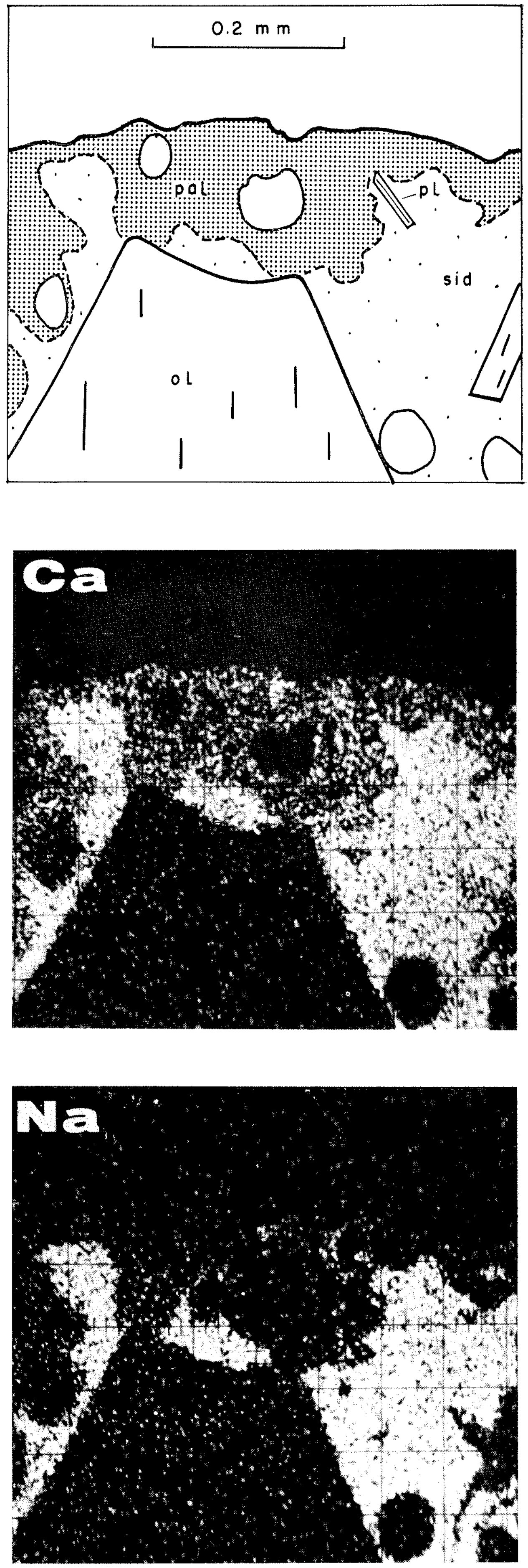


Fig. 6. Electron beam scanning images showing distribution of Ca and Na in a sideromelane grain and its palagonite rim (sample taken in Sept. 1969). For reference see the drawing of the grain at top; sid=sideromelane, pal=palagonite, ol=olivine and pl=plagioclase.

up of volcanic glass, mainly of basaltic composition (Jóhannesson 1960, Sigbjarnarson 1969), the main part of the remainder being crystalized fragments. Provisional analyses of Icelandic soil indicate that the rock constitutents (i.e. the glass) easily undergo chemical weathering (Jóhannesson 1960, p. 10). It seems probable that palagonitization of basaltic glass is an important chemical process leading to the formation of soil in Iceland. If so, the process works at temperatures as low as approx. 0—15°C which are common mean monthly temperatures near the surface in Icelandic soil (Helgason 1961). Average temperatures in tephra at 5 cm depht on the northern coast of Surtsey during April—Augst 1968 varied between 5—17°C (Sigtryggsson 1970).

DISCUSSION

In the case of Surtsey it is possible to follow closely the processes of consolidation and palagonitization of basaltic tephra and describe how they take place under the local physical conditions. So far the story reads as follows:

Nov. 14, 1963 — April 4, 1964: The tephra forms in phreatic eruptions and is composed of fresh basaltic glass (sideromelane) with dispersed fragments of hyalobasalt.

August 1966: Consolidation has started in surface layers in a few places but proceeds slowly.

April 1968: Heating of tephra with emanations of steam discovered in the eastern mound close to the newest lava craters.

Sept. 1969: A part of the tephra is found to be consolidtaed to tuff within the thermal field at surface temperatures of approx. 60°—100°C. Palagonitization has commenced in a few places. Dispersed opal precipitations.

August 1970: The area of consolidated tephra is now about 12.000m², whereas the extension of the thermal field is similar as in 1969. Precipitations of opal common.

April 1971: Consolidation proceeds to give a more dense rock; the first zeolite (chabazite) is discovered in the tuff.

As mentioned above the author did not have the opportunity to visit Surtsey in 1968 but it is probable that consolidation and possibly palagonitization had already started by that time, i.e. only one half to one year after heating up of the tephra.

From the above it then follows that the product of submarine, basaltic, phreatic eruptions near sea-level is finegrained tephra made up of sideromelane glass. This glass is subject to palaganitization, which is a post-eruptional process taking place at relatively low temperatures, cf. Noe-Nygaard (1940), Jónsson (1961) and Hay & Iijima (1968). It is provisionally suggested that palagonitization in the tephra-pile above sea-level in Surtsey proceeds at 100°C in the presence of abundant water, and that the temperature falls gradually in the uppermost ½—1 m of the layers. The surface palagonitization described in this report has proceeded at approx. 6°—100°C and 1 atm. pressure. At these conditions it is only a matter of 3—4 years before dense palagonite tuff (Icel. móberg) is formed with precipitations of opal and chabazite.

Some workers (e.g. Bonatti 1965) have suggested that palagonite is formed at the time of eruption as the result of reaction between the hot melt and water. Both in the case of the Surtsey eruption and the subglacial 1934 Grímsvötn eruption (Noe-Nygaard 1951) it is established that the glass content of the erupted tephra was sideromelane with no traces of palagonite.

The mechanism of the heat transfer of the thermal field has not been established. As mentioned before, the heating is obviosuly connected to the lava craters. It is possible that cooling feeder dykes and small intrusions at high level are the main sources of the heat. Sigvaldason (1968) has suggested that pillow lavas buried beneath the tephra pile serve as the main heat source for the process of palagonitization of pyroclastic material in subaquatic volcanoes of specific structure. In the case of Surtsey the presence of pillow lavas has not been proved. If pillow lava is found at the base of Surtsey it will have been formed in the first days of eruption, i.e. in Nov. 1963. The thermal field was, however, not discovered before 1968 and seems to be closely related to the 1967 lava-craters, it is therefore not probable that the hypothetical pillow lava is the heat source.

Research on the formation of palagonite rocks in Surtsey will be continued during the next several years. All investigations have so far been limited to the surface of the tephra formation. The value of this research could be greatly enlarged by drilling a hole into the tephra in order to find out how palagonite is formed at depth both above and below sea-level.

ACKNOWLEDGEMENTS

This research has been financially supported by the Icelandic Science Fund and the Surtsey Research Society. Prof. A. Noe-Nygaard is thanked for encouragement and for providing laboratory facilities at the Mineralogical Museum,

Copenhagen. Dr. G. E. Sigvaldason critically revised the manuscript.

References:

Bonatti, E. 1965: Palagointe, hyaloclastites, and alteration of volcanic glass in the ocean. Bull. Volc. 28; 3—15.

Hay, R. L. & Iijima, A. 1968: Nature and origin of palagonite tuffs of the Honolulu group on Oahu, Hawaii. Geol. Soc. Am. Mem. 116; 331—376.

Helgason, B. 1961: Athuganir á hitastigi jarðvegs á Íslandi. Nátt.fr. 31; 97—113.

Hoppe, H. J. 1940: Untersuchungen an Palagonittuffen und ihre Bildungsbedingungen. Chemie d. Erde 13; 484—514.

Jakobsson, S. 1968: The geology and petrography of the Westman Islands. A preliminray report. Surtsey Progr. Rep. IV; 113—129.

Jóhannesson, B. 1960: The soils of Iceland. Univ. Res. Inst. Reykjavík.

Jónsson, J. 1961: Some observations on the occurrence of sideromelane and palagonite. Bull. Geol. Inst. Univ. Uppsala 40; 81—86.

Noe-Nygaard, A. 1940: Sub-glacial volcanic activity in ancient and recent times. Fol. Geogr. Dan. Tom 1, no. 2.

Noe-Nygaard, A. 1951: Materials from the eruption in Grímsvötn, Vatnajökull, in 1934. Fol. Geogr. Dan. Tom 1, no. 4.

Norrman, J. O. 1970: Trends in postvolcanic development of Surtsey Island. Surts. Res. Progr. Rep. V; 95—112.

Peacock, M. A. 1926: The petrology of Iceland. Part I. The basic tuffs. Trans. Roy. Soc. Edinb. 55; 51—76.

Sigbjarnarson, G. 1969: Áfok og uppblástur. Nátt.fr. 39; 68-118.

Sigtryggsson, H. 1970: Preliminary report of the results of meteorological observations on Surtsey 1968. Surts. Res. Progr. Rep. V; 119—120.

Sigurgeirsson, Th. 1966: Geophysical measurements in Surtsey carried out during the year of 1965. Surtsey Res. Progr. Rep. II: 181—185.

Sigvaldason, G. E. 1965: Um rannsókn á gosefnum frá Surtsey. Nátt.fr. 35; 181—188.

Sigvaldason, G. E. 1968: Structure and products of subaquatic volcanoes in Iceland. Contr. Min. Petr. 18; 1—16.

Thórarinsson, S. 1965: The Surtsey eruption: Course of events and the development of Surtsey and other new islands. Surtsey Res. Progr. Rep. II: 117—124.

Thórarinsson, S. 1968: Síðustu þættir Eyjaelda (The last phases of the Surtsey eruption). Nátt.fr. 38; 113—135.

Thórarinsson, S., Einarsson, Th., Sigvaldason, G. E. & Elísson, G. 1964: The submarine eruption off the Westman Islands 1963—64. Bull. Volc. 27: 1—11.

Report on Geothermal Observations on the Island of Surtsey

By
AEVAR JÓHANNESSON

On 5th, 6th, 7th and 8th of August 1970, observations and measurements of geothermal heat were made under the auspices of the Institute of Science of the University of Iceland on the island of Surtsey.

Measurements were made in those parts of the island that have been created from tuff, and the temperature was also measured in the upflow of gases in the lava and near the craters.

Measurements in the tuff were effected by the plunging of a metal bar down to the depth that was to be measured, and a mercury thermometer was inserted in the hole to the bottom. Thermometer readings were then taken after three minutes had elapsed.

This method enabled temperatures to be measured down to a depth of 140 cm in those areas where the tuff had not substantially hardened. In other areas the tuff had hardened so much that it was not possible to penetrate more than a few tens of centimetres down, and in a few places it was not even possible to reach a depth of 10 cm, for there the tuff was so compact that it could hardly be cut up with a shovel.

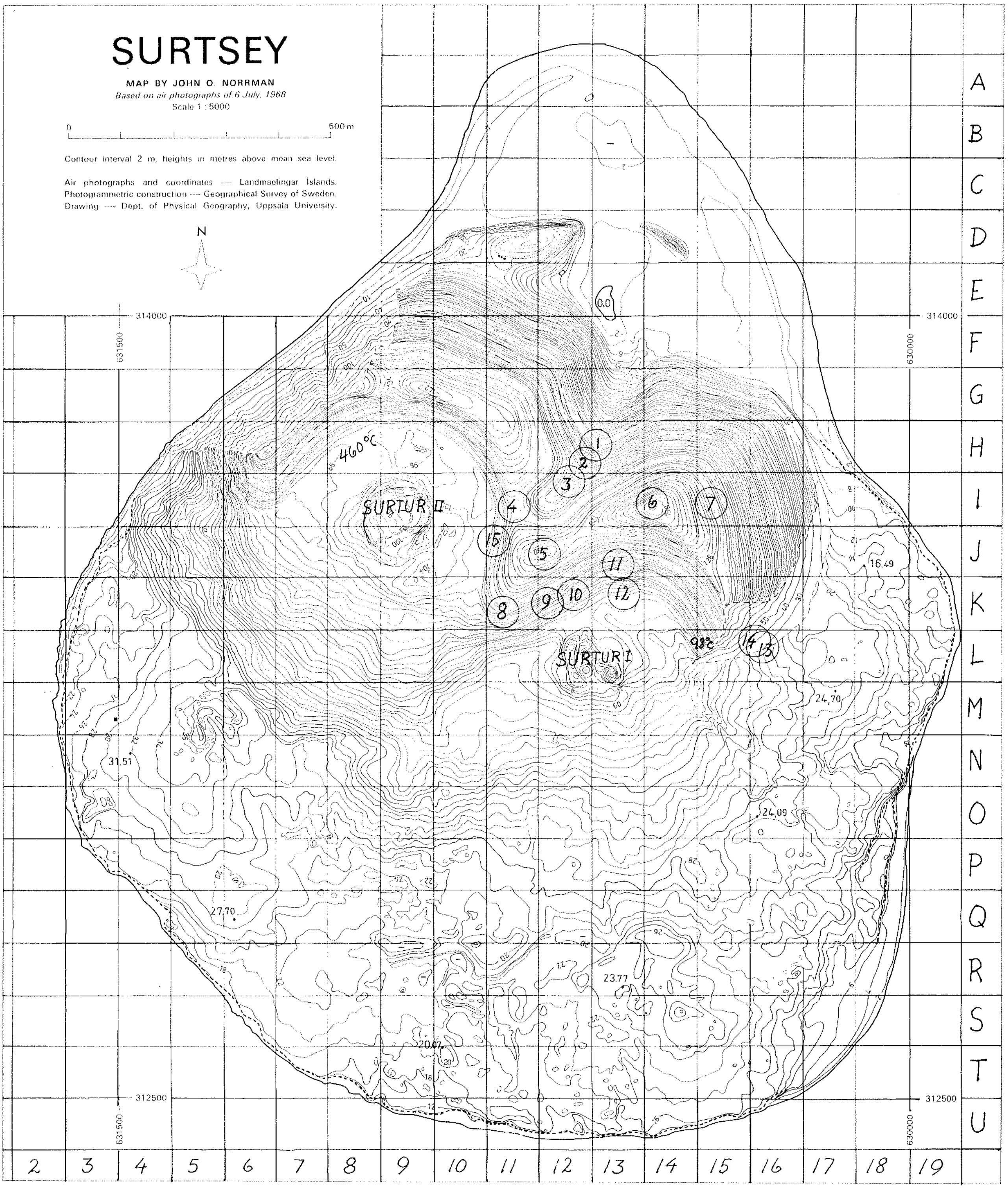
Measurements in the lava were made by inserting a thermometer into an upflow vent, from which hot air or steam was rising, and then making readings a little later. In these measurements mercury thermometers were used for temperatures below 250°C, and "Rototherm"-type thermometers for higher temperatures. In a few places both types of thermometers were used, between which there was quite good correspondence, although the "Rototherm" thermometer seemed to show a rather lower temperature, or approx. 10—20°C.

GEOTHERMAL HEAT IN TUFF

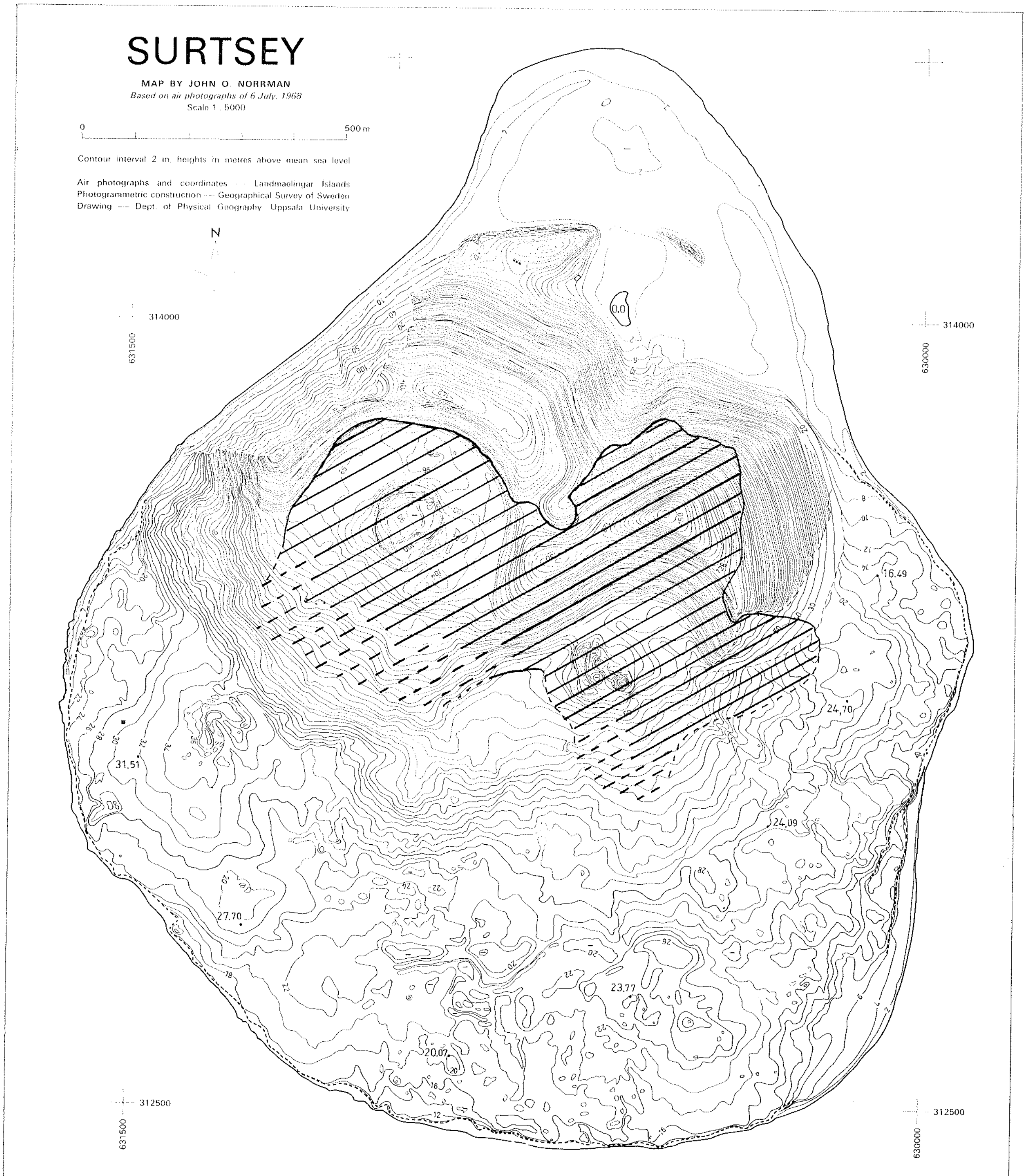
Geothermal heat in tuff is found in an extensive area in the mountain north of Surtur I, which will be referred to here as "Strompfjall". The heat is in the whole interior of the crater bowl of Surtur I and extends over the rim down the mountain slope below the "Strompur" crater and a little way down from the summit in a northeasterly and easterly direction, but in quite a large area in the lower part of the mountain and at its base no increase in heat could be measured at a depth of 60—100 cm.

Above the measurement points 13 and 14 there is an almost perpendicular tuff wall, from which vapour could be seen ascending over an area of about 100 sq m close to the top of the mountain, but on the top itself above, a little to the north, no steam was visible. In the easternmost part of the crater bowl of Surtur I the heat is probably greatest, for 98°C was measured there at a depth of less than 10 cm a few tens of metres up the slope. A little higher up in that area some 100°C hot steam issues from a small N—S running fissure. A little to the north of that point is an area where the tuff has hardened so much that samples can only be taken with a hammer and chisel and it mostly resembles concrete.

As already mentioned, the whole of the crater bowl of Surtur I is more or less hot. This thermal area extends uninterruptedly along the mountain ridge between Surtur I and Surtur II, the



Measuring points



The thermal area on Surtsey

vapours issuing from the small craters on the slope being 98—100°C hot. In the hollow to the east of Surtur II there is considerable heat, which extends up to the gap east of the crater, but just to the north of there no heat was found, nor was there any in the hollow above the Svartagil ravine. To the north, in the crater hollow of Surtur II, there is little heat in the tuff, in some places none at all, and nowhere does it extend more than a few tens of metres from the edge of the lava. For instance, at a distance of 20 m from the edge of the lava only 12°C were measured at a depth of 100 cm, whereas at the edge of the lava steam with a temperature of 105°C came up. This was to the N—E of Surtur II. In other places there was sometimes a little heat at a distance of up to 35 m from the edge of the lava.

Despite numerous observations it was not possible to detect heat in the mountains "Bunka" or "Bondi" (Bauer's Peak), and although the watchers on Surtsey thought they had seen vapours rising at certain places, no heat was found there on closer investigation. In those areas devoid of geothermal heat, the temperature is very even at differing depths, or 10—12°C.

In the thermal areas the increase in heat with increasing depth is on the whole fairly even, but its rate varies in the different observation places. The temperature appears to cease to rise when the boiling-point of water is reached, which may be at a depth of from less than 10 cm up to a few metres, if the increase in heat is proportionately as great in the colder areas, such as where 100°C is reached at a depth of less than one metre. Nowhere in the tuff was a temperature higher than 100°C measured with any certainty, but where the lava and the tuff meet water vapour rose up at one point with a temperature of 105°C.

A distinct difference is emerging in the appearance of those areas where the tuff is hot and in those where there is no underlying heat. In cold areas the tuff is still loose and weathers very rapidly. It can be seen that mud streams have run down the slopes, leaving behind screes in the upper part and filling themselves up in the lower part near the foot of the mountain. Near the summit large boulders are strewn about in many places, either lava bombs or sometimes fragments of sediment thrown up with the tuff, from around which loose material has since been weathered away and they have remained on their own. In such places it is sometimes possible to find plagioclase crystals several cm in diameter. If the tuff here is dug into with a shovel, it is found to be loose and fresh. Where there has been any significant geothermal heat, the tuff has been much less weathered. The contours of the mountain are smoother, and the mud streams have not managed to make any deep impression. Loose volcanic material has been blown away less, so that the surface boulders are not so conspicuous. If diggings with a shovel are attempted there, the tuff is found to be firm and in some places even so hard that it cannot be dug into.

Of particular interest are the measurements at points 1, 2 and 3, taken on 6th August. Then it was necessary to find a depth of about 100 cm in order to reach a temperature of 100°C. On the next day, 7th August, measurements were again made at the same points, when the heat had risen so much that a depth of only 10 cm was necessary to reach the same temperature, and the surface of the tuff was very hot. This increase in temperature occurred at measuring points 1, 2 and probably also 3, and it was maintained on all the days during which measurements were continued. On 15th August measurements were again made there, and the temperature was the same as on the days 7th to 9th August.

In many places in the tuff where there is underlying heat, fissures running in various directions are visible. They appear, however, to lie mostly in a circle around Surtur I, though there are many exceptions to this and they are difficult to trace for more than short distances. Hot steam rises from some of these fissures, though by no means everywhere, and heat does not seem to be limited to such places. It is strange what sharp boundaries these thermal areas have, there being only a few metres between places where there is considerable heat and places where no heat could be measured. Compared with observations made in the summers of 1968 and 1969, the thermal areas have spread out in most directions, e.g. no heat could be detected in the Svartagil ravine at measuring points 1, 2 and 3 in the summer of 1969.

A sort of carpet of steam is frequently visible above the thermal areas, thus showing roughly where their boundaries lie.

The temperature of the tuff appears to be the deciding factor as to whether palagonitization occurs. Where there has been heat for a number of years, various intermediary stages can be found in the palagonitization, and in places where this change is most advanced the tuff may be considered to have become firm rock. Where no geothermal heat is to be found, not the slightest change in that direction can be detected.

THE CRATER BOWL OF SURTUR I

In the easternmost part of the crater bowl of Surtur I there is much heat. About 10 metres below the top of the lava a temperature of 92°C was measured approx. 5 cm below the surface. It was not possible to penetrate deeper. In the upper part of the slope a temperature of 100°C was measured in steam emission from a N—S lying fissure. There were a few other fissures there having a similar direction. A little to the west on the slope there is a large area of hardened tuff. At the bottom of the crater bowl are many vents, from which steam rises. Measurements showed that the temperature of the steam is between 60 and 80°C, usually 70—75°C. Farther out in the lava there is also some emission of steam, mainly along the fissures. There the heat is in some places considerably higher, maximum 220°C, and the emission seems to contain less vapour, or even very little. Measurements of the steam emission from small craters in the inside of the crater bowl gave readings of 98—100°C generally.

THE CRATER BOWL OF SURTUR II

There is much heat in the lava all around Surtur II. Steam rises in many places at the edges of the lava, where it adjoins tuff. Steam also rises at some distance inside the lava areas. The temperature in the steam vents is in most places 70—90°C, although a measurement of 105°C was found in one place. Furthermore, hotter currents of drier air rise up from the lava, but they are less conspicuous. There the temperature is usually above 100°C, and at one place northwest of Surtur II a temperature of about and above 400°C, maximum 460°C (390-410-430-460), was measured at a few points. This place is on a fissure parallel to the edge of the lava, about 20—30 m inside the lava beneath "Bóndi" (Bauer's Peak). Quite a strong air current ascends from the fissure, and it is accompanied by slight hissing sounds. No vapour is visible in this air, and there is not much precipitation around the fissure, mostly a stony crust, reddish-brown in colour.

It seems that the lava-shield of Surtur II has subsided somewhat since the end of the eruption there, for parallel fissures go through the lava a little distance inside the edge of the lava; the lava-shield has probably subsided in the middle and the fissures formed all around it, though they cannot everywhere be traced and it is difficult to estimate the total extent of the subsidence. In some of these fissures there is heat, in others not, and the fissure in which the temperature is highest may be considered a part of this fissure system, though irregularities in formation cannot be detected there.

South, also southeast and east, of Surtur II there is heat in a quite extensive area, temperatures of about and above 200°C, maximum 220°C, being measured in a few places. At a place that has been named "The Grill" there is a very big upflow of heat, and the quantity of air is so great that it makes a whistling sound, but a temperature of only 150°C was measured there.

Southwest of Surtur II there is also heat in the lava in a large area, and this thermal area extends quite a long way down into the lava. One measurement taken there showed a temperature of more than 250°C, but there was insufficient time to make more detailed observations.

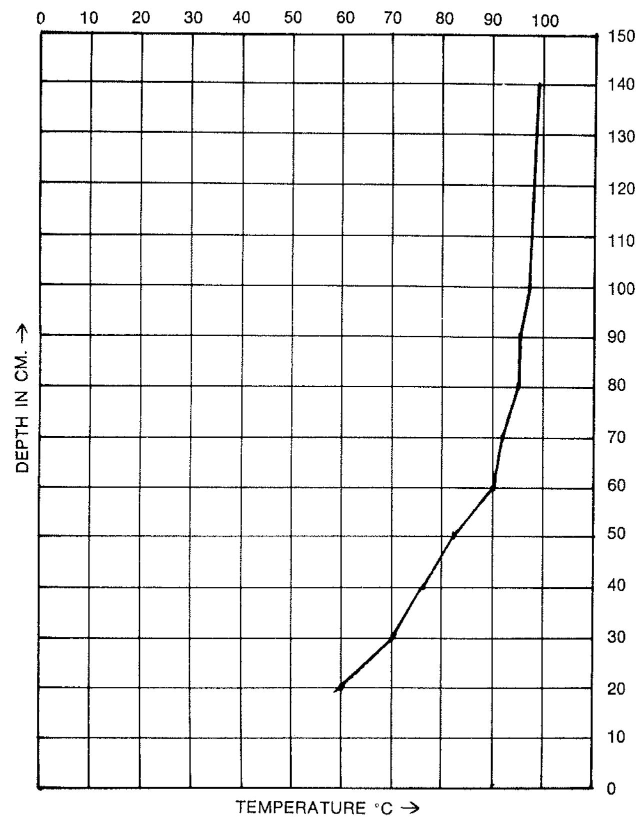
Where there is much heat in the lava, sand and tephra that has been blown into the area has changed colour and become red. This change seems to occur at a temperature of about 100°C and just below, when a layer of red sand often forms under a dark surface layer, whereas lower down, where the heat is greater, the sand is again dark. Moisture also seem to be necessary for the production of this change.

In the Strompur crater a temperature of 98°C was measured in the steam emission, and at a distance of 30 m from the crater the temperature in the tuff was 90°C at a depth of 30 cm, but it was not possible to penetrate any deeper at that place.

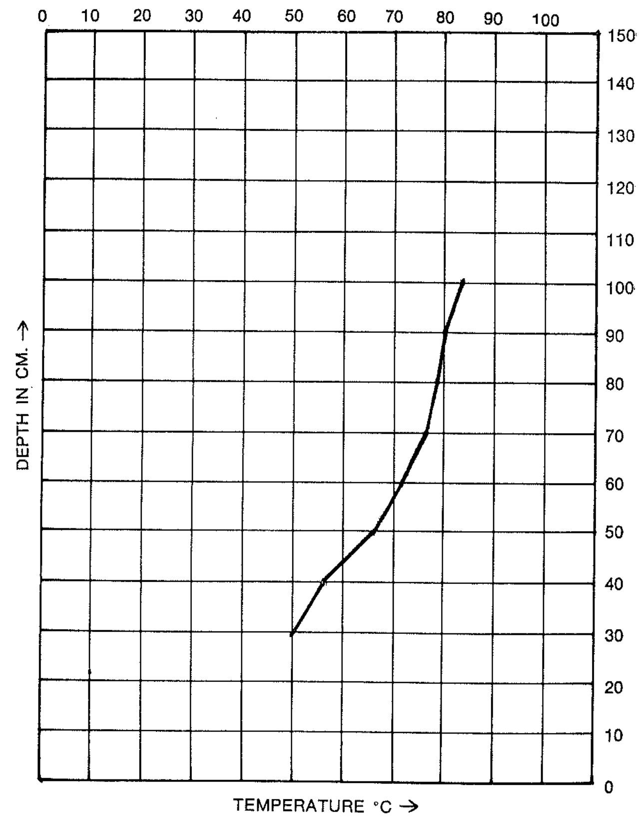
BRIEF SUMMARY OF CONCLUSIONS

There is much and widespread geothermal heat active on Surtsey, both in the lava and in the tuff. In the tuff the temperature does not exceed 100°C at measurable depths, but in the lava it is in same places much higher. The thermal areas in the tuff appear to be spreading, but it is difficult to say whether the same applies to the heat in the lava, as measurements from immediately preceding years are not available. The areas around both the main craters are still hot, and seem to have changed little in the past two years. Where the temperature is greatest in the lava northwest of Surtur II, it is so high that it can only be due to glowing material(s). The heat in the tuff seems to be the decisive factor as to whether it is transformed into firm rock or not.

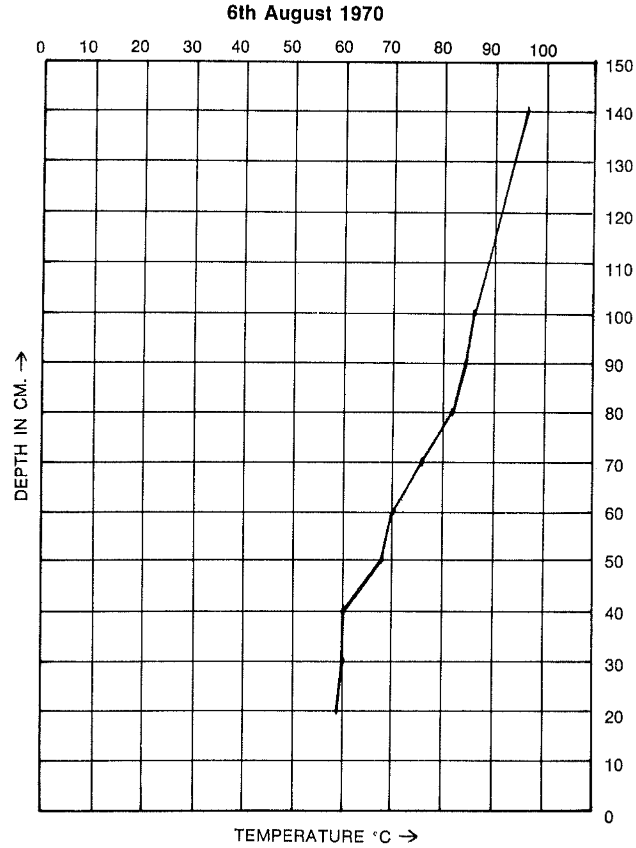
MEASURING POINT 1
6th August 1970



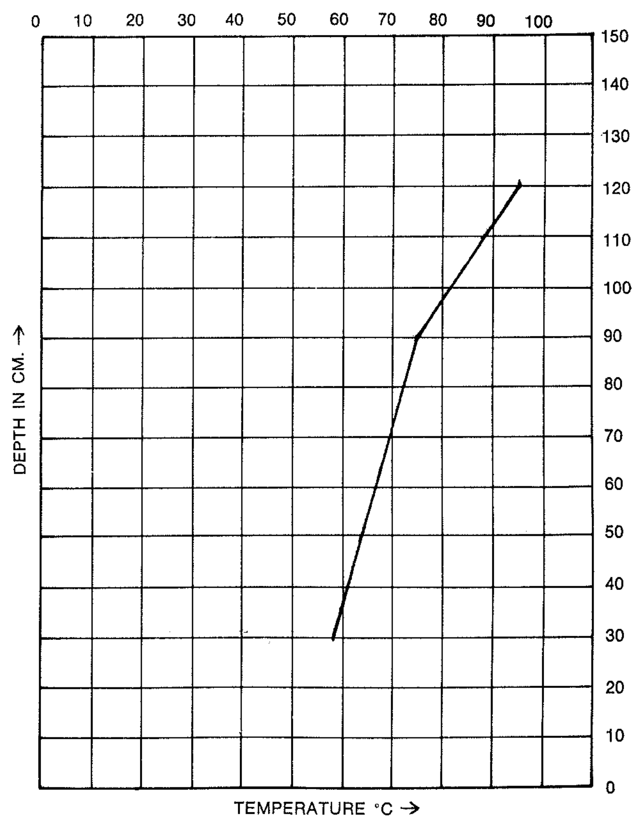
MEASURING POINT 4
6th August 1970



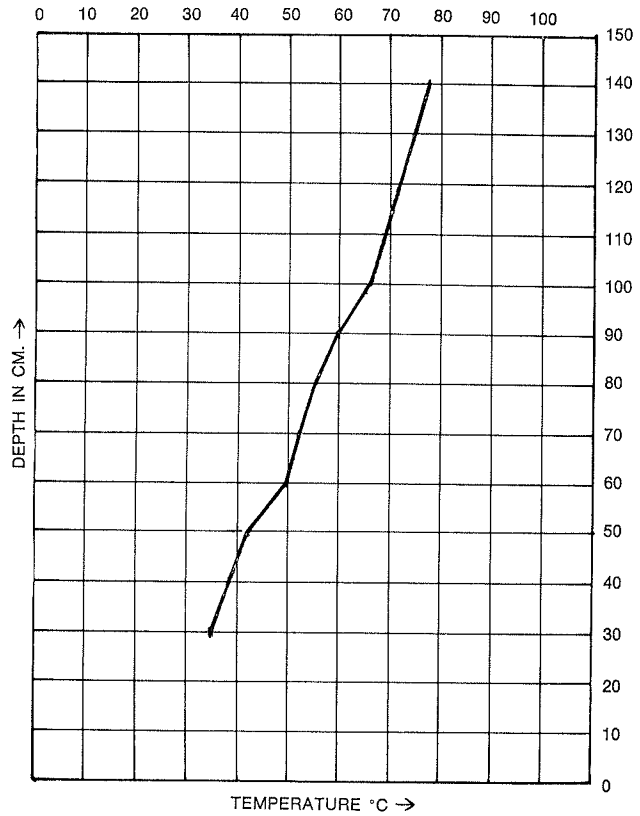
MEASURING POINT 2
6th August 1970



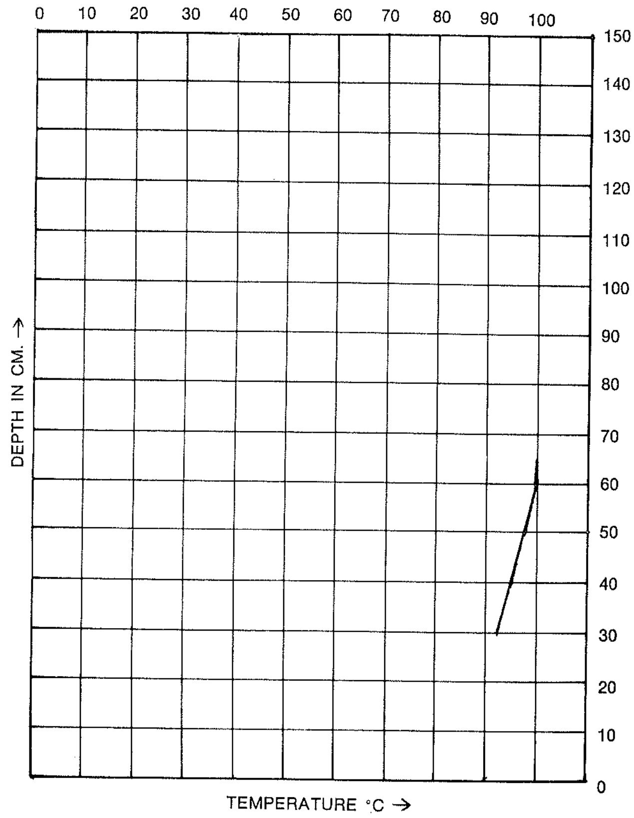
MEASURING POINT 7
7th August 1970



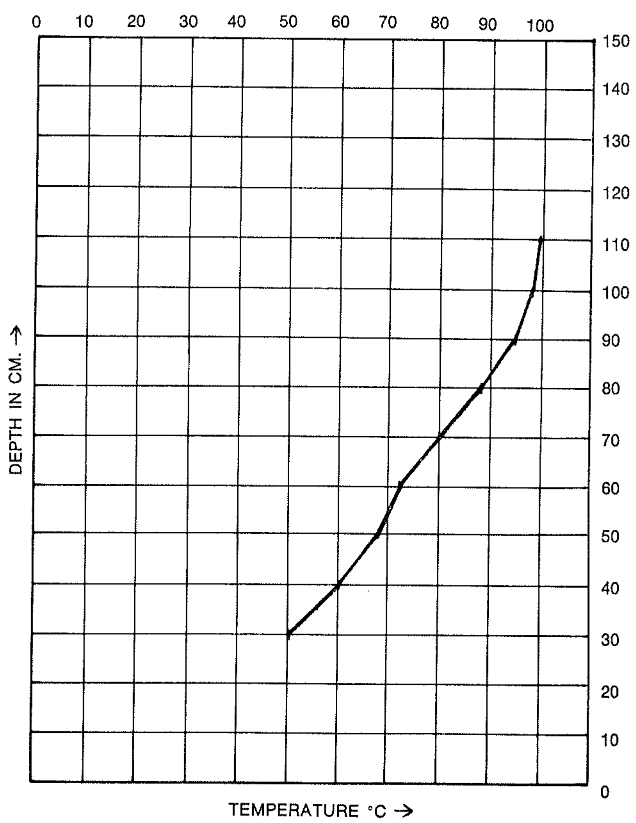
MEASURING POINT 11
7th August 1970



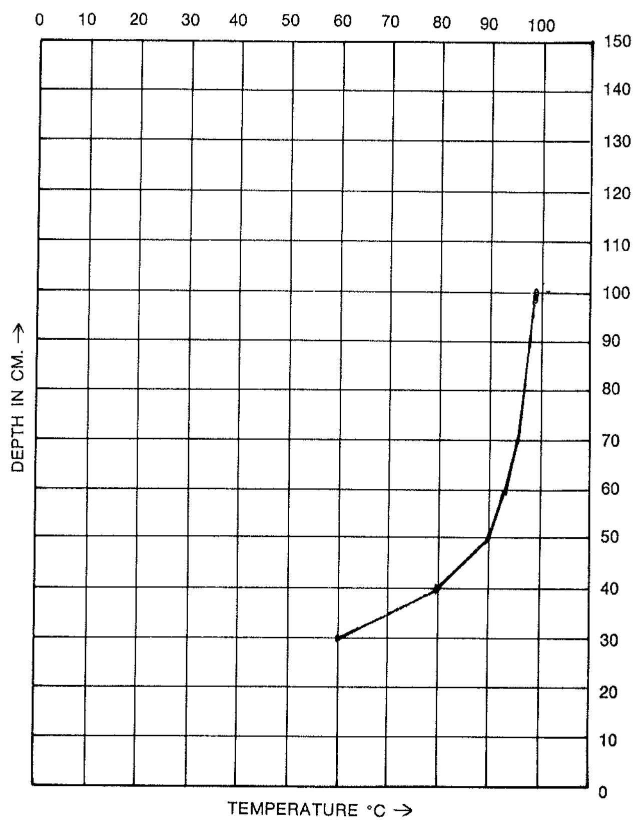
MEASURING POINT 14
8th August 1970



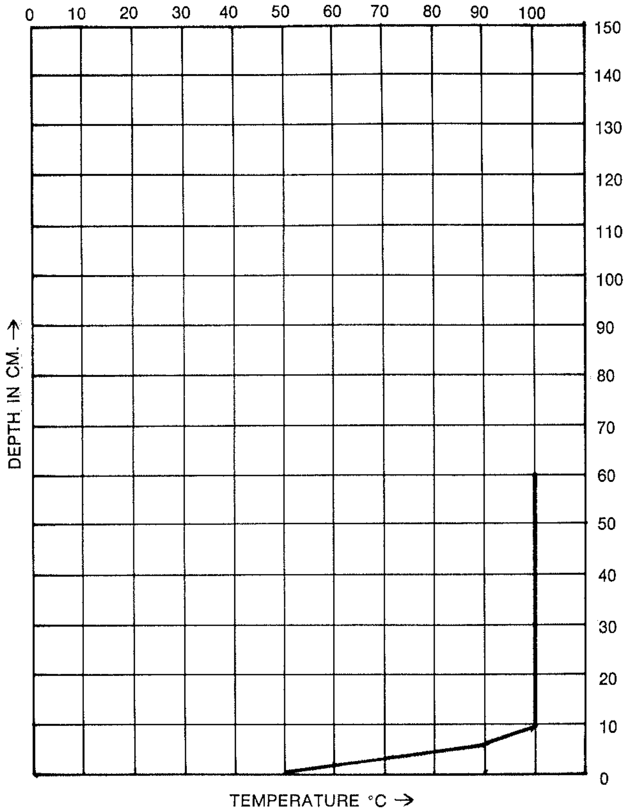
MEASURING POINT 13
8th August 1970



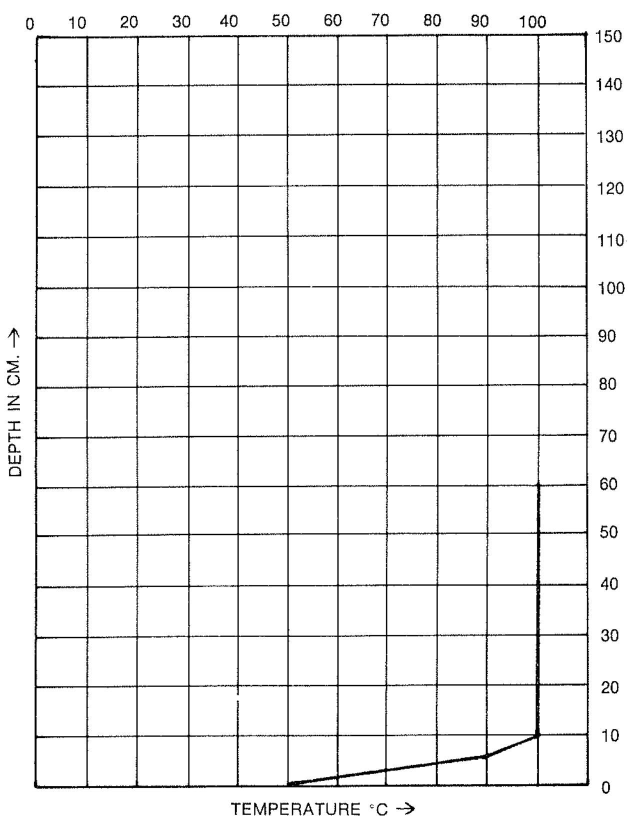
MEASURING POINT 15
8th August 1970



MEASURING POINT 16
7th August 1970



MEASURING POINT 17
7th August 1970



Measuring Points:

Measurement 1 In the Svartagil ravine, square H-13, graph.

Measurement 2 In the Svartagil ravine, square H-12, graph.

Measurement 3 In the Svartagil ravine, square I-12, temperature at a depth of 30 cm: 30°C.

Measurement 4 In the gap above Svartagil, square I-11, graph.

Measurement 5 On the peak south of the beginning of Svartagil where squares J-11 and J-12 overlap. Temperature at a depth of 25 cm was found to be 57°C.

Measurement 6 On the high peak of Strompur mountain, square I-14. The temperature at a depth of 40 cm was 86°C, at 50 cm 90°C.

Measurement 7 East of measuring point 6, square I-15, graph.

Measurement 8 SSE of measuring point 5, square K-11. Temperature at a depth of 47 cm: 85°C.

Measurement 9 Just west of the small crater on K-12. Temperature at a depth of 40 cm: 65°C.

Measurement 10 Just east of the same small crater on K-12. Temperature at a depth of 40 cm: 65°C.

Measurement 11 Taken at the Kirkjugígur crater, square J-13, graph.

Measurement 12 On the level ground below measuring point 11, square K-13. Temperature at a depth of 40 cm: 20°C.

Measurement 13 At the foot of the slope below the tuff cliff where L-15 and L-16 overlap, graph.

Measurement 14 At same place as measurement 13, though 9 m higher on the slope, graph.

Measurement 15 West of measuring point 5 at the foot of the slope, square J-11, graph.

Measurement 16 At same place as measurement 1, graph.

Measurement 17 At same place as measurement 2, graph.

In addition to these measurements, very many observations of temperature in the tuff were taken in order to determine the boundaries of the thermal areas. Furthermore, the temperature of the steam emissions was measured in many places.

Coastal Development of Surtsey Island, 1968–69

By
JOHN O. NORRMAN
Department of Physical Geography, Uppsala University, Sweden

INTRODUCTION

The aim of the geomorphological field investigations carried out in July 1969 was to determine coastal changes during the last year and to map the submarine morphology around the island by echo sounding. The latter object will be dealt with in a separate report.

Height stations used in the 1968 aerial survey were remounted and air photographs were taken by Landmaelingar Íslands on 3 August, 1969. These photographs have been utilized for a new photogrammetric model by which the coast line and the northern ness have been mapped.

THE CLIFF COAST

The retreat of the lava cliffs have continued to smooth the coast line of the pear-shaped island but the bulge on the eastern coast still remains (Fig. 1).

Fig. 1. Aerial photograph of Surtsey Island, 3 August 1969. A, western boulder terrace. B, eastern boulder terrace. Photograph by Landmaelingar Íslands.

The rate of abrasion during the last year has been far less than during the preceding year. As before the strongest activity is found along the southern coast. There is still no sign of development of a stable abrasion platform. Storm waves hit the vertical cliff walls almost unbroken. Even under fairly good weather conditions with 1-m to 2-m waves the wave action is effective (Fig. 2).

THE BOULDER TERRACES

The western terrace below the tephra cliff of the crater Surtur Junior (Fig. 1) is still intact and protects the cliff base (c. Norrman 1970. Fig. 5). The terrace has been slightly broadened in its southern part by deposition of lava blocks which have been broken off the cliff immediately south of this area.

Tephra material that falls from the cliff wall or is deposited on the terrace by mud flows is swept into the sea by wave swash (Fig. 3).

The eastern boulder terrace (Fig. 4) was somewhat narrowed in the winter 1967—68 (Norrman 1970, Fig. 3). Most of the material seems to have incorporated in the narrower but higher terrace that in fact contained more material than before. The shift in shore line position was explained as a resultant effect of the severe abrasion of the cliff to the south of the beach that made this lava cliff retreat 140 m.

Last year the retreat in the same cliff area was 35—40 m (Fig. 8). By this a cross section of the terrace became exposed to waves from the south and the main part of the terrace material was washed out. In the central part of the terrace the shore has been cut back 50—55 m (Fig. 8).

THE NORTHERN NESS

The ness was originally built up by spits that fringed a tectonically formed lagoon. This lagoon occupied the entire area inside the narrow tephra ridge which at present is found in the central part of the ness (cf. Figs. 1 and 7). For details of this development and further references see Norrman (1970).

The wave built ness mainly consists of gravel and sand but within this mass there are tongues and ridges made up of large boulders. The present ridge-shaped high berm along the western beach is mainly composed of boulders.

By re-sorting in the swash zone, especially along with shift of shore position, sandy material has gradually been removed from the beach. It has partly slid down the steep offshore slope and partly been washed inland by up-rush overtopping the berm. In July 1969 only about 150 m of the foreshore at the northern end of the ness was covered with sand.

The transportation along the eastern and western coasts that supplies material to the ness has not kept pace with the loss of material from its beaches. As in 1967—68 the main shore retreat is found along the eastern beach (Fig. 8, cf. Norrman 1970, Fig. 7). During the last year considerable amounts of material have been swept over the berm into the central parts of the ness (Fig. 5).

The major changes in the morphology can be found by comparison of contour maps depicting the situation in July 1968 and August 1969 (Fig. 6). The lagoon inside the narrow tephra ridge has disappeared because the whole area has been filled up with sand to a height above mean sea level. The aggradation is mainly caused by swash floods but wind transported silt and sand and material carried by mud flows from the slopes of the tephra cones have also contributed to this development (Fig. 7).

The berms along the eastern and western shores have been built out towards the north at 4 to 5 m above m.s.l. Thus the ness is now encircled by a more than 4 m high barrier. The closed depression inside the barrier with a height of less than 2 m indicates the site of a lagoon that was filled up with sand in the winter 1967—68 (Norrman 1970, Figs. 7 and 8).

AREAL CHANGES

From photogrammatric maps in the original scale of 1:5,000 areal changes form 6 July 1968 to 3 August 1969 have been calculated (Fig. 8). The following figures were obtained for different parts of the coast.

The lava cliff of the southern and southwestern coast		Loss 6.3 hectares
The lava cliff of the eastern coast		Loss 0.9
The northern ness and the western boulder terrace		Gain 1.1
		Loss 5.9
	Net	Loss 4.8
The eastern boulder terrace		Loss 4.8
	Total	Loss 16.8 hectares

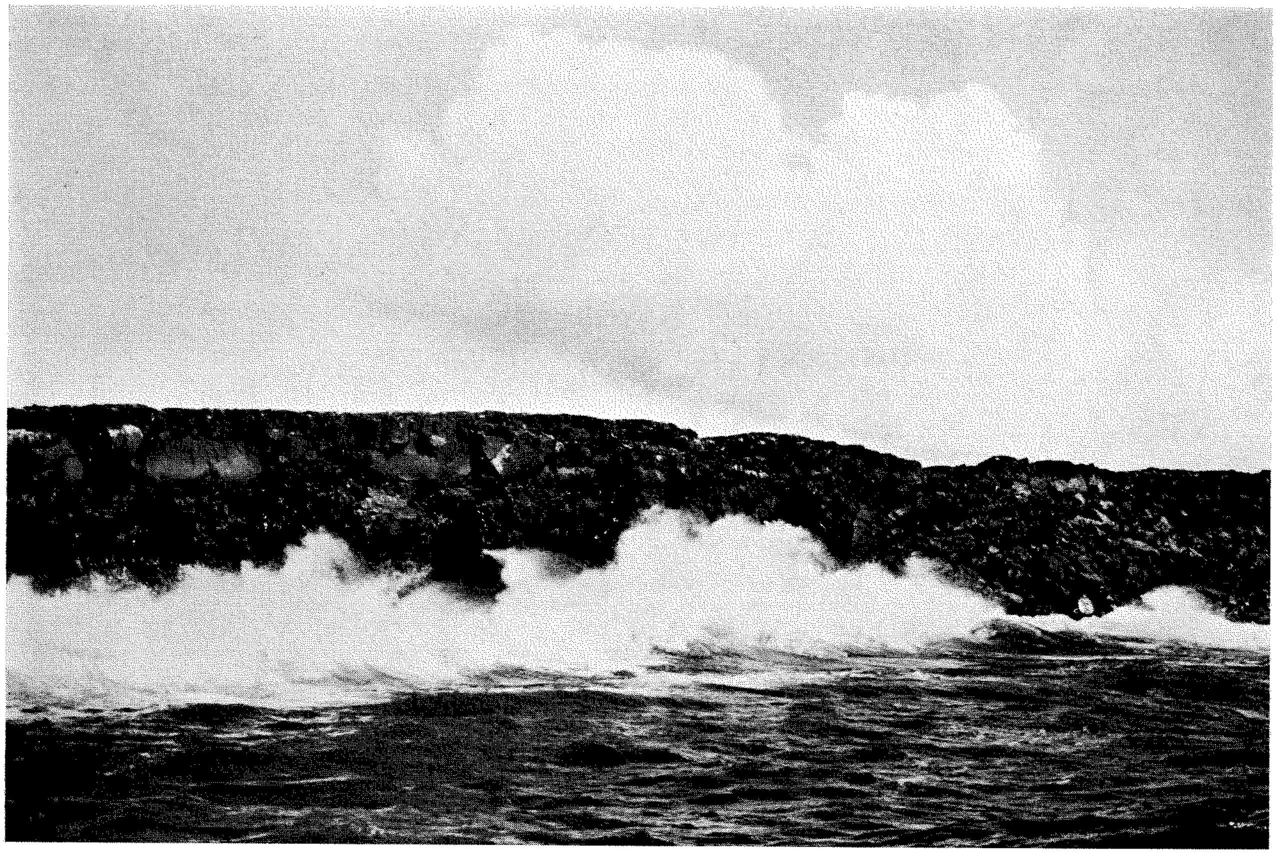


Fig. 2. A 2-m wave breaking on the lava cliff of the southern coast. The height of the cliff is 16 m.

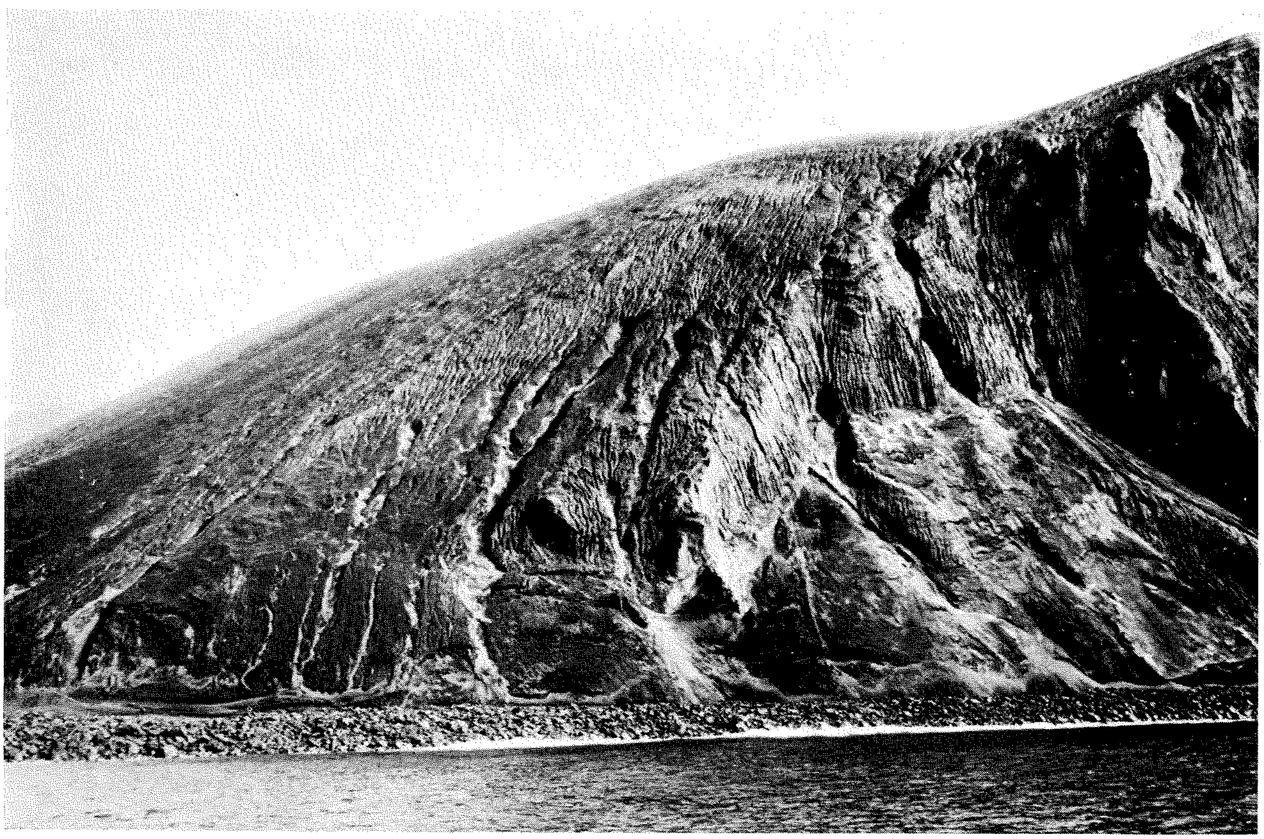


Fig. 3. The northern part of the western boulder terrace below the cliff of the crater Surtur Junior.

Fig. 4. The eastern boulder terrace viewed from its southern end. The lava surface seen in the foreground is situated at 10 m above m.s.l.

Fig. 5. Stream pattern from swash that has overtopped the berm of the northern ness.

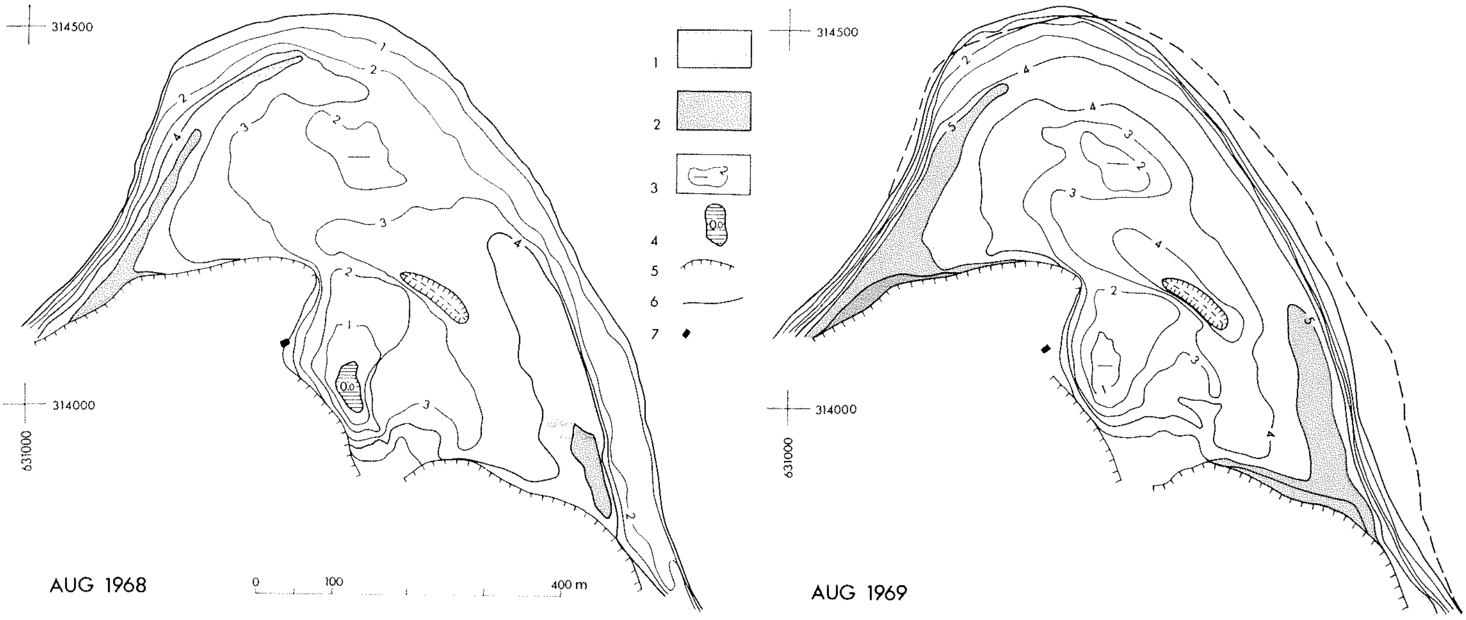


Fig. 6. Photagrammetric map of the northern ness as developed on 6 July 1968 and 3 August 1969. Contour interval 1 m. Heights above m.s.l. 1, Areas between 4 and 5 m above m.s.l. 2, Areas above 5 m. 3, Closed depression. 4, Lagoon. 5, Base of tephra slopes. 6, Shoreline of 6 July 1968 in the right hand map. 7, Research station. Photogrammetric construction by the Geographical Survey of Sweden based on photographs by Landmaelingar Íslands and ground control by the author.

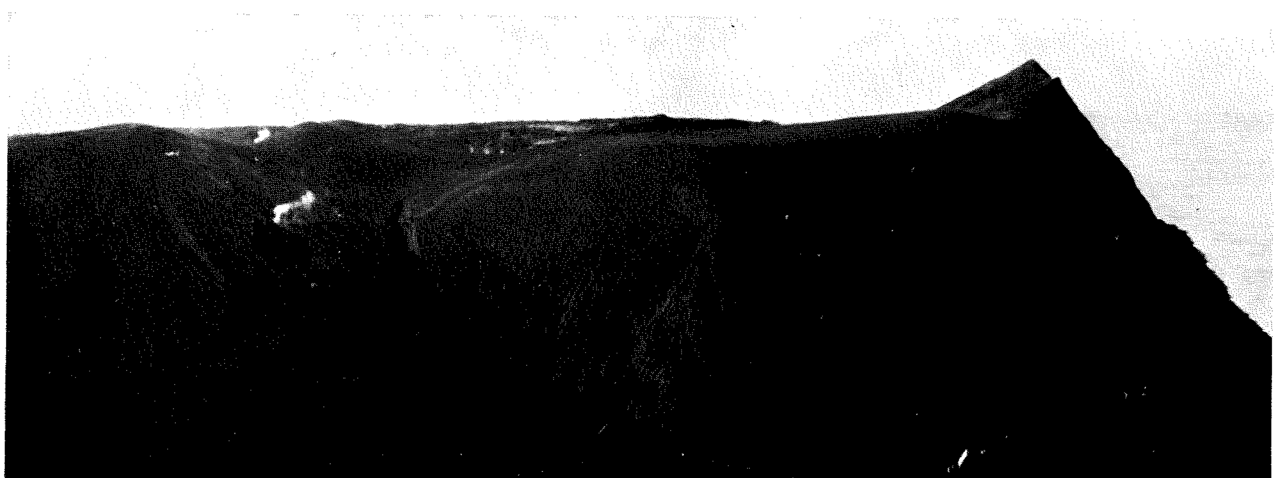


Fig. 7. Aerial view of the eastern and central parts of the northern ness. Note the site of the former lagoon at the research station and the vapor steaming from a vent on the slope of Surtur Senior. Photograph by J. D. Friedman, September 1969.

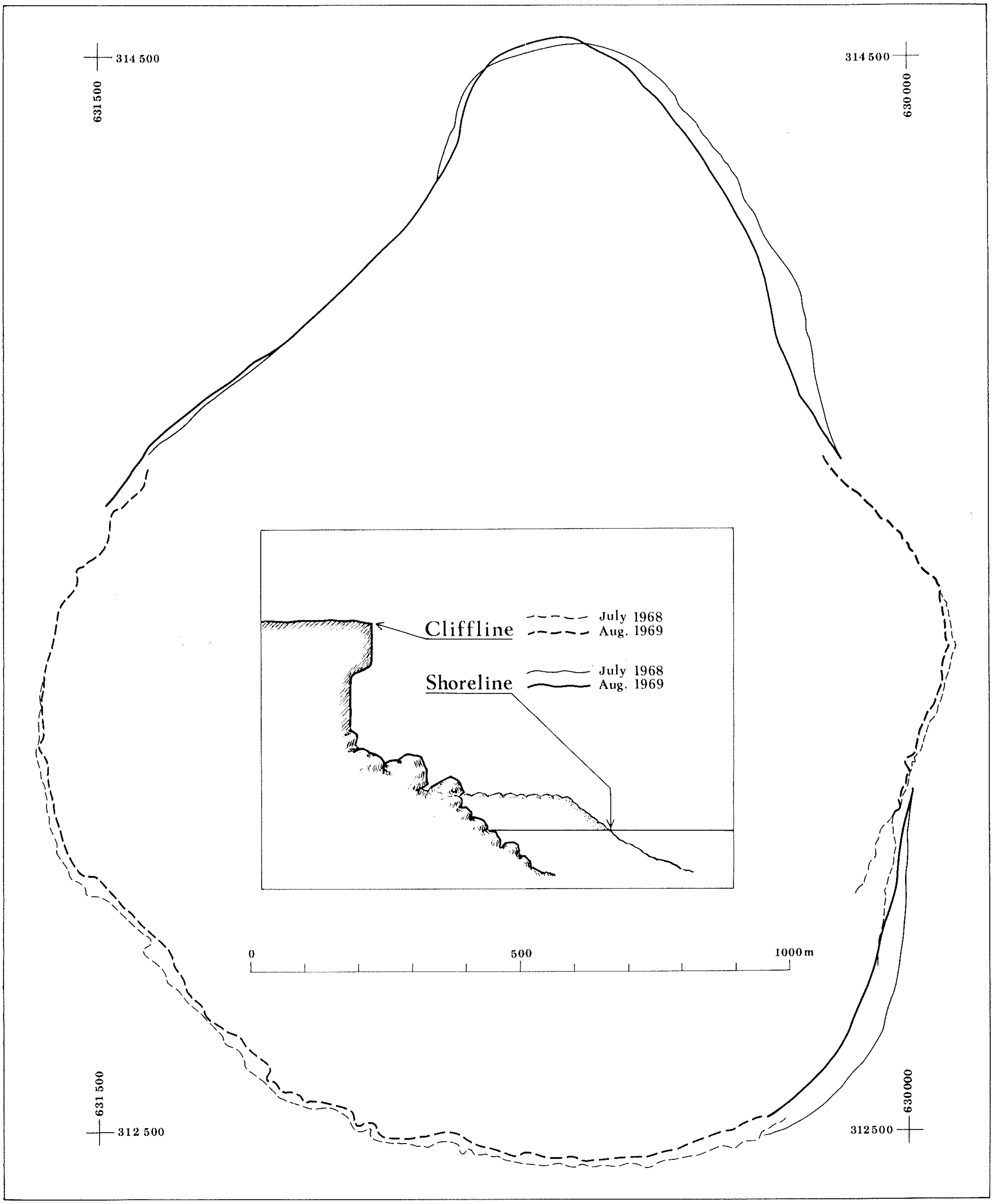


Fig. 8. Cliffline and shoreline of 6 July 1968 and 3 August 1969. Photogrammetric construction by the Geographical Survey of Sweden based on aerial photographs by Landmaelingar Íslands and ground control by the author.

CONCLUDING REMARKS

The trends in postvolcanic development outlined in the report on geomorphological activities in 1968 have not changed. The retreat of the lava cliffs have continued and there is still no evidence for considerably more resistant rocks to exist closer to the craters. The variation in yearly cliff reterat is of an order that can be expected from variable weather conditions.

The reduction of the size of the northern ness and the aggradation in its central part continues. It does not seem likely that the fringing berm will grow much higher.

The future coastal development should be followed up by yearly aerial surveying and photo interpretation.

ACKNOWLEDGEMENTS

The 1969 investigations were supported by the Swedish National Science Research Council (NFR contract 2160-5) and the Surtsey Research Society, Reykjavík. The photograph of Fig. 7 was kindly provided by Dr. Jules D. Friedman of the U.S. Geological Survey. The figures were drawn in the Department of Physical Geography, Uppsala University, by Miss Kjerstin Andersson and Miss Kerstin Kvist.

Author's address: Dept. of Physical Geography, Box 554, S-751 22 Uppsala, Sweden.

Refernce:

Norrman, J. O., 1970: Trends in Postvolcanic Development of Surtsey Island. Progress Report on Geomorphological Activities in 1968. Surtsey Res. Progr. Rep. V.

Coastal Changes in Surtsey Island, 1969–1970

By
JOHN O. NORRMAN
Department of Physical Geography, Uppsala University, Sweden

INTRODUCTION

The present report is essentially based on comparisons of air photagraphs from 3 August 1969 and from 3 September 1970. The shore characteristics of 1969 have been dealt with in a previous report (Norrman 1972). For a general description of the coastal morphology of the island the reader is referred to the report on the 1968 field season (Norrman 1970).

Mounted height stations on the lave used in earlier aerial surveys (Norrman 1970, 1971) could be identifed in the 1970 photographs and they have formed the geodetic basis for a new photogrammetric mapping of the island. Unfortunately, all height stations placed on the sands of the northern ness had been swept away and thus the absolute height of the contour lines of the ness is less precise than in previously published maps.

As the morphological changes in the inland areas are small it was found unnecessary to print a new complete height contour map of the island. Separate copies of the map published in 1970, which was based on photographs from 1968, can be obtained from the author.

In this report only net changes over the 13-month period up to September 1970 are presented as no data have been collected within this period of investigation. Along the high energy beaches of Surtsey large short term variations exist in shore-line position and in morphology. Thus a comparison of the conditions on a day in one year and another day in the next year does not tell much about the morphological activity level nor necessarily about trends in shore development. Along the lava cliffs where there is only coastal retreat the changes from one year to another more simply reflect the summed effect of a series of events.

THE CLIFF COAST

It is of interest to note that during the last two years there has been very little abrasion in the northernmost part of the lava cliff on the western coast. This 300 m long cliff faces WNW and it ends in the north at the large scar formed in the tephra cliff of the crater of Surtur Junior (cf. Fig. 1). Because of the temporary stability of this lava cliff there has also been small changes in the adjacent tephra wall.

The west facing lava cliff further to the south has suffered much more from wave attack. The maximum cliff retreat is 40 m and the average retreat about 25 m (cf. Fig. 2).

The most strongly affected cliffs are found along the southwestern shore. The maximum retreat is 50 m and the average retreat 35 m. The highest lava cliffs are found here. The vertical wall of the projecting head at the northern end of this coast is 32 m high. It will probably take many years before any much higher lava cliffs are formed because along the south-western and southern coasts the inland slope of the lava surface is low.

Along the southern coast there has again been less abrasion. The maximum retreat is 40 m and the average figure about 20 m.

On the eastern coast the bulge formed by lava flows from Surtur Senior is gradually vanishing by a steady but comparatively slow cliff retreat. The retreat during the last year amounts to ca. 10 m.

THE BOULDER TERRACES

According to the air photographs there are only small changes along the western boulder terrace. A heavy shadow in the photographs precludes studies of any morphological details (Fig. 1).

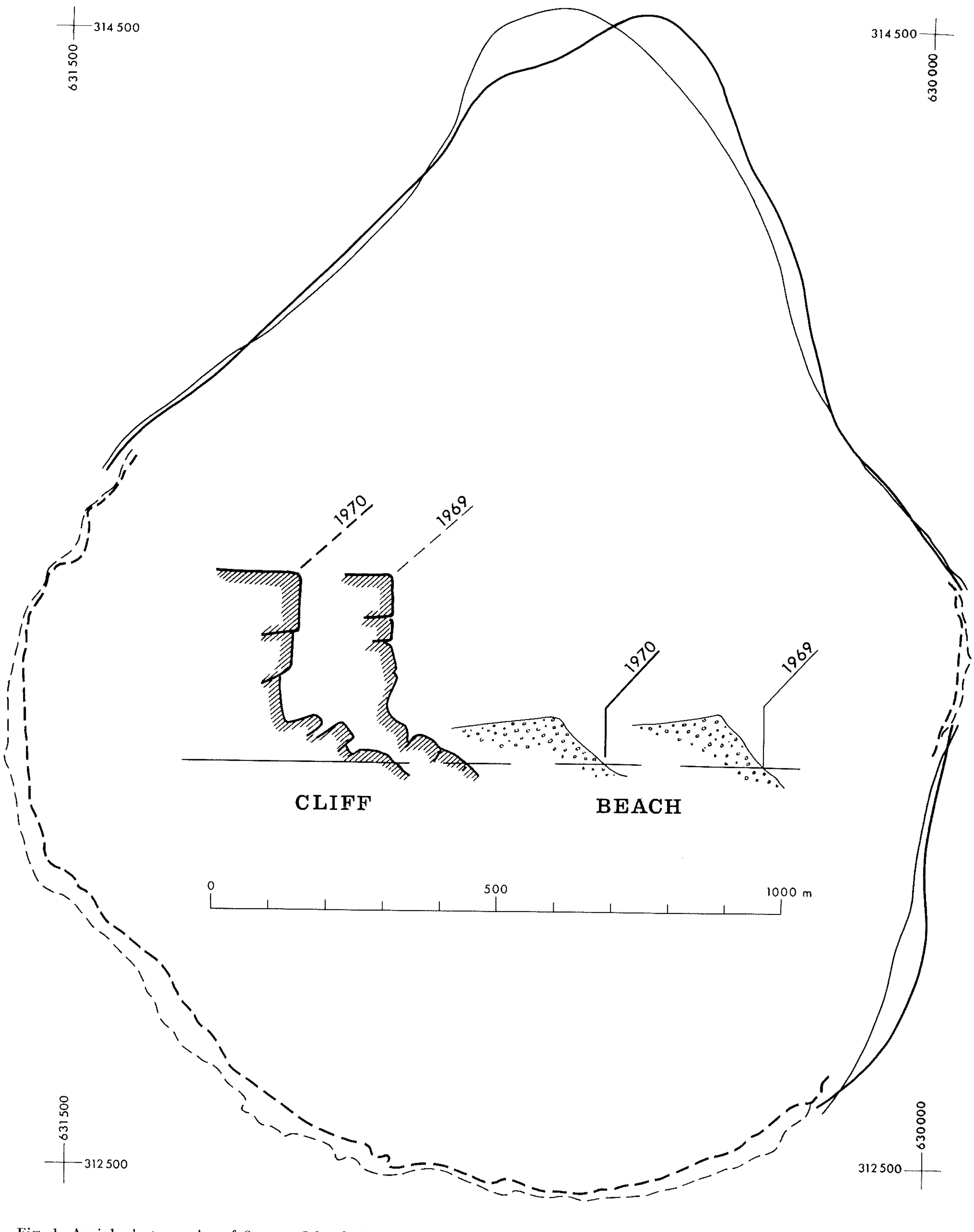


Fig. 1. Aerial photography of Surtsey Island, 3 September 1970. Photograph by Landmaelingar Íslands.

Fig. 2. Cliffline and shoreline of 3 August 1969 and 3 September 1970. Photogrammetric construction by the Geographical Survey of Sweden based on aerial photographs by Landmaelingar Íslands and ground control by the author.

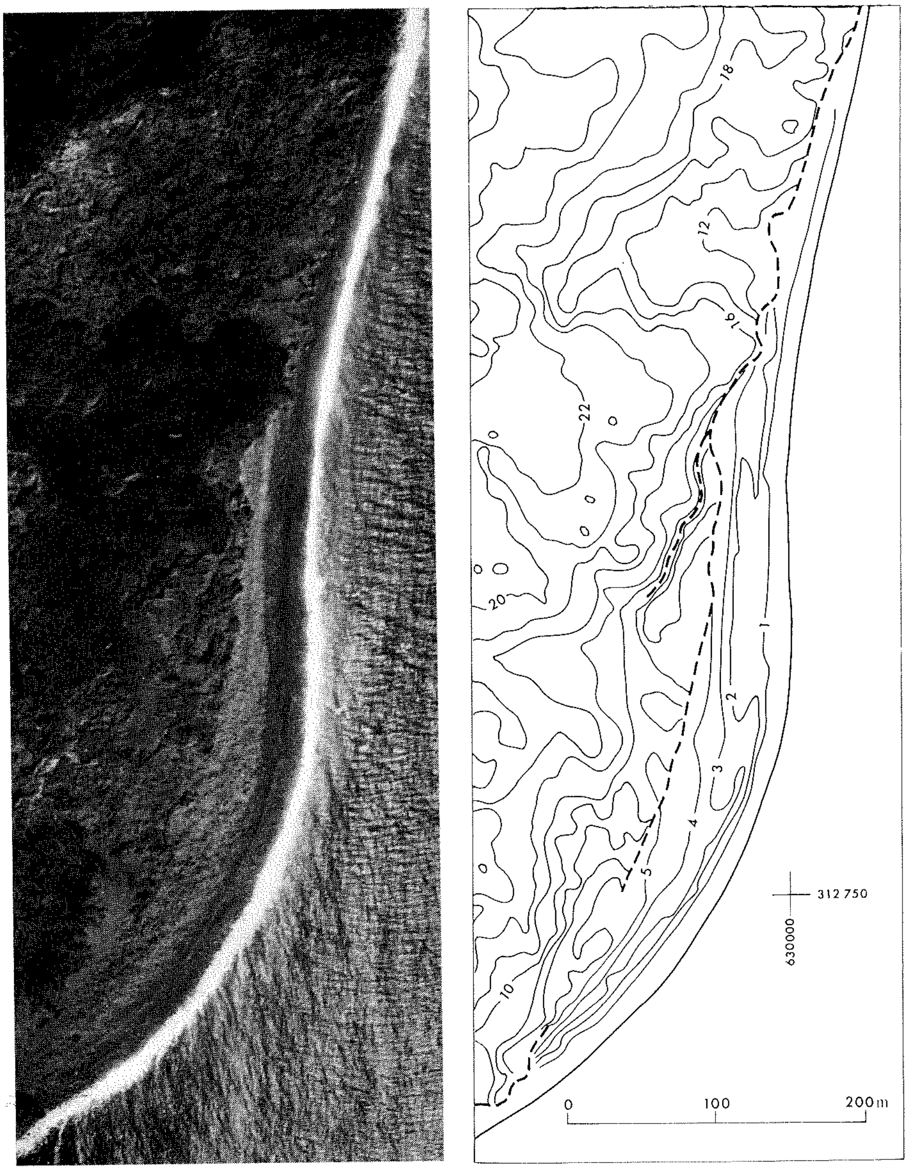


Fig. 3. Aerial photography and height contour map of the eastern boulder terrace, 3 September 1970. Contour interval in shore area (below cliffline) is 1 m, above cliffline 2 m.

The eastern boulder terrace has changed considerably. The year before it was severely eroded (Norrman 1972). The terrace has now been broadened in its northern and central parts where the shore line again follows the 1968 contour.

A steep terrace slope along the shore towards the north was noted in 1968 and has previously been discussed (Norrman 1970, p. 100). The same slope is developed in the 1970 morphology as can be seen from a contour map (Fig. 3). The average slope along the southern half of terrace is 1:50, and in the northern half 1:150.

THE NORTHERN NESS

A comparison between contour maps of 1969 and 1970 (Fig. 4) reveals considerable changes in the morphology of the ness.

The 1969 map depicts a situation where rather balanced wave activities on the eastern and western beaches have formed a more than 4 m high barrier which encircles the entire ness. The two depressions mark the positions of former lagoons which have been filled up by sand deposited by floods.

The 1970 map reflects a strong wave activity from the west, that has significantly changed the shore line configuration by a shift over to the east. Swash overtopping the high western berm has flooded the ness and the height contours dramatically illustrate how draining flood water has eroded the eastern berm and cut a wide channel across the ness.

AREAL CHANGES

From photogrammetric maps in the original scale of 1:5,000 areal changes from 3 August 1969 to 3 September 1970 have been calculated (Fig. 2). The following figures were found for different parts of the coast.

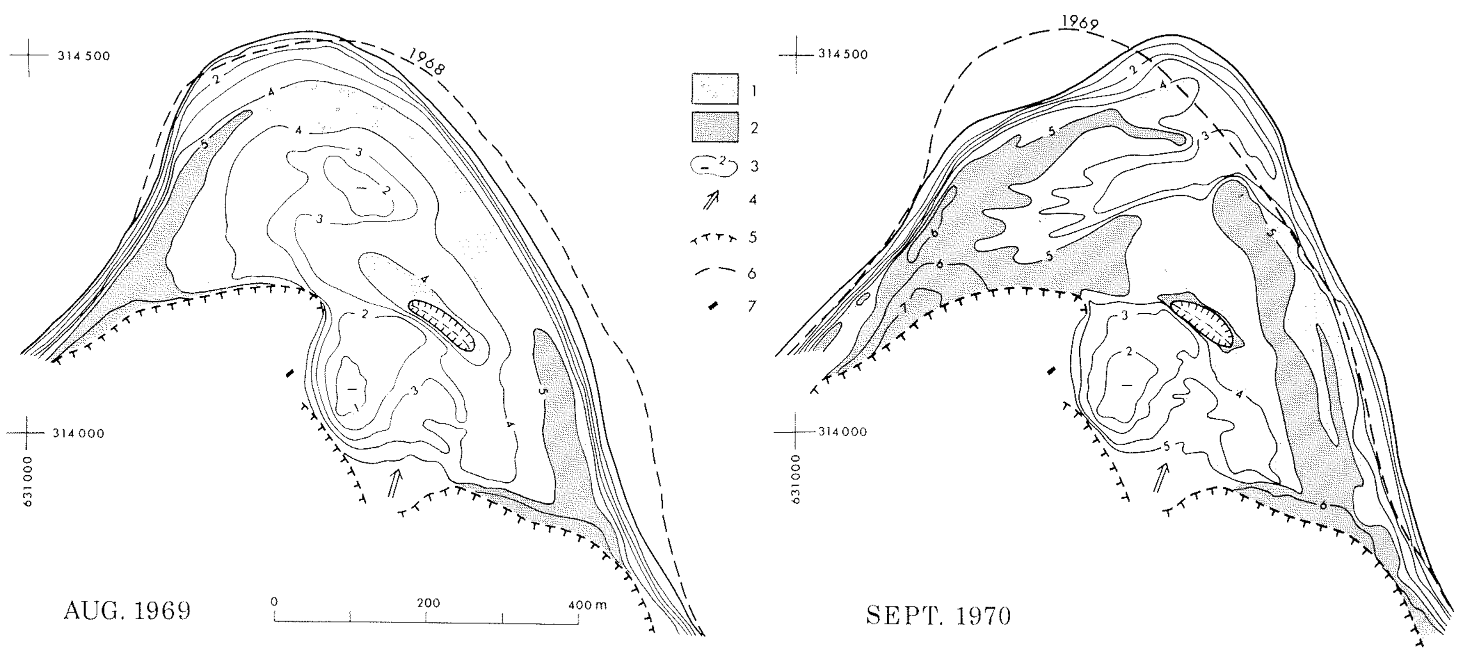


Fig. 4. Photogrammetric maps of the northern ness as developed on 3 August 1969 and 3 September 1970. Contour interval 1 m. Heights above m.s.l. 1, Shore areas between 4 and 5 m above m.s.l. 2, Shore areas above 5 m. 3, Closed depressions. 4, Lava flow of 1967. 5, Base of tephra slopes. 6, Shorelines of 1968 and 1969 respectively. 7, Research station. Photogrammetric construction by the Geographical Survey of Sweden based on photographs by Landmaelingar Íslands and ground control by the author.

The lava cliff of the southern and southwestern coast		Loss 6.2 hectares
The lava cliff of the eastern coast		Loss 0.3
The northern ness and the western boulder terrace		Loss 2.5
		Gain 5.2
	Net	Gain 2.7
The eastern boulder terrace		Loss 0.2
		Gain 1.7
	Net	Gain 1.5
	Total	Loss 2.3 hectares

The loss of lava land on the southern and southwestern coast is almost the same as in the previous year (6.3 hectares) but then there was also a considerable retreat of the beaches which made the total loss amount to 16.8 hectares.

CONCLUDING REMARKS

In the year 1969—1970 the lava cliffs of Surtsey Island have been broken down by wave attacks at the same rate as in the last years. The position of the wave-built northern ness shifts with the direction of storm winds.

There is still a depression left in the innermost part of the ness that has not yet been filled up by flood transportation and wind drift.

The rate of coastal changes makes it essential to have air photographs taken at least once a year. For further photogrammetric work it is necessary to make complementary levellings for new height stations along the northern coast.

ACKNOWLEDGEMENTS

The 1970 investigations were supported by the Swedish National Science Research Council (NFR contract 2160-9) and the Surtsey Research Society. The figures were drawn in the Department of Physical Geography, Uppsala University by Miss Kjerstin Andersson.

References:

Norrman, J. O., 1970: Trends in Postvolcanic Development of Surtsey Island. Progress Report on Geomorphological Activities in 1968. Surtsey Res. Progr. Rep. V.

— 1972: Coastal Development of Surtsey Island, 1968—69. Progress Report on Geomorphological Activities during 1969. Surtsey Res. Progr. Rep. VI.

Textural Analysis of Surtsey Tephra
A Preliminary Report

By

MICHAEL F. SHERIDAN

Associate Professor, Department of Geology, Arizona State University, Tempe, Arizona 85281

INTRODUCTION

Textural analysis of modern pyroclastic and hydroclastic deposits provides a means of characterizing ancient tephra units. The grain size distribution is also useful for interpretation of transportation and deposition mechanisms related to the various modes of eruption and emplacement. Iceland has several historic volcanic centers that are well suited for textural analysis of tephra. Surtsey is one of the best of these centers because of the well documented eruption, good exposures, unique environment, and wealth of interdisciplinary studies. The information herein reported is a result of the Boston College – NASA expedition to Iceland during June, 1970.

SAMPLES

Tephra samples were collected from nine widely separated points on both Surtur I and Surtur II (Figure 1). In most cases samples were taken from a single bed (5 to 10 cm thick) with an attempt to represent a variety of stratigraphic levels and textures. The size of the tephra samples ranged from 140 g to 286 g. Because of the reconnaissance nature of the expedition and the relatively few samples, it should be assumed that some textural varities exist that fall outside of the range of those sampled. Two samples of beach sands (7 and 8 of Figure 1) were collected from the berm 5 m above the high tide line for comparison with the tephra.

TABLE 1

Size Distribution Parameters of Surtsey Tephra

Sample No.	Mø	Sorting	Skewness
1	1.54	2.49	0.31
2	1.01	2.99	0.37
3	1.65	2.37	0.10
4	0.24	3.05	0.44
5	1.83	3.12	0.13
6	2.19	2.76	0.21
9	1.50	3.31	0.21
10	0.79	2.56	0.27
11	−0.07	2.13	0.35
average	1.19±.71	2.75±.37	0.27±.11

RESULTS

Standard mechanical analyses were made using U. S. Standard 8-inch screens with a one phi intervel for the tephra and U. S. Standard 3-inch screens with a one-half phi interval for the beach sand. Because of its many advantages, the size class used in this paper is the phi unit (Ø) proposed by Kumbein (1934). Results of the size analyses are presented in Figures 2 and 3. The data are plotted with phi vs. cumulative weight

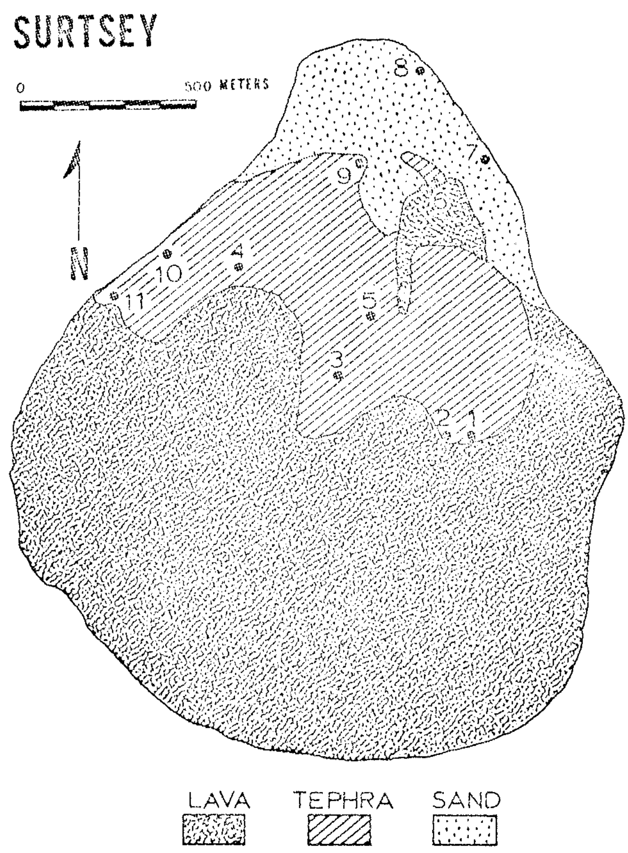


Fig. 1. Location of samples. Base from Norrman, 1970.

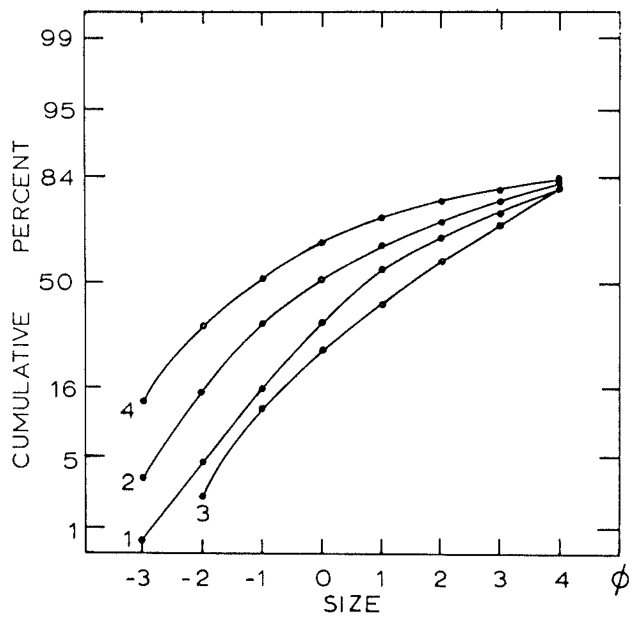


Fig. 2. Size data of tephra samples 1 through 4. Similarity of size distribution is obvious.

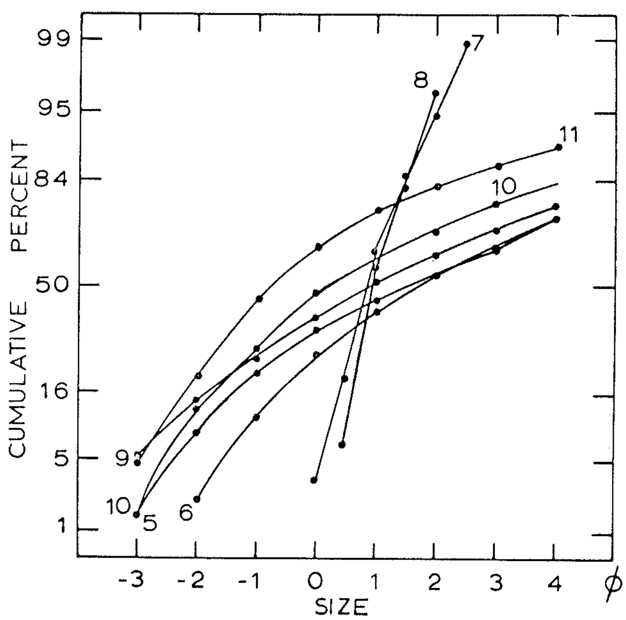


Fig. 3. Size data of tephra samples 5 and 6, and 9 through 11. Note the different plots for beach sand samples 7 and 8.

percent on a log-probability scale so that the statistical parameters can be readily evaluated (Krumbein, 1937, 1938). The size distribution parameters of Inman (1952) of tephra are listed in Table 1 and of beach sand in Table 2. The median size of 1.19 phi and very poor sorting of 2.75 are useful in characterizing this tephra and distinguish it from subaerial or water worked volcanic particles.

Certain characteristics of the particle size distribution are evident. The tephra curves are all of the same general form. Rather than a log-normal distribution, that would be a straight line on probability paper (Visher, 1969), the curves are convex upward representing the fine-skewed nature of the distribution. This general form is characteristic of a Rosin's law distribution (Kittleman, 1964) and suggests that the original distribution produced by mechanical crushing during eruption has not been greatly modified by secondary transportation, by dispersal in a fluid medium, by base-surge, or by water reworking.

To illustrate the unique sorting character of this tephra, two samples of beach sand were analyzed. These sands are composed of the same materials as the tephra, but they have been reworked and sorted by wave action. This difference is seen graphically in Figure 3 as well as by the median size of 0.02 phi and moderate sorting of 0.47.

TABLE 2

Size Distribution Parameters of Surtsey Beach Sand

Sample No.	Mø	Sorting	Skewness
7	−0.06	0.52	0.17
8	0.08	0.42	0.31

CONCLUSION

The Surtsey tephra represent a unique environment that can be adequately characterized by grain-size parameters. The samples are very poorly-sorted and fine-skewed. The distribution more closely approximates a Rosin's distribution than a log-normal distribution. Profitable study in the future would involve detailed sampling to test for the range in grain size and to relate changes in mean size and sorting to stratigraphic level. It would also be meaningful to compare other submarine tephra cones with Surtsey.

References:

Inman, D.L., 1952, Measures for describing the size distributions of sediments: Jour. Sed. Petrology, v. 22, p. 125–145.

Kittleman, L. R., 1964, Application of Rosin's distribution in size frequency analysis of clastic rocks: Jour. Sed. Petrology, v. 34, p. 483–502.

Krumbein, W. C., 1934, Size frequency distribution of sediments: Jour. Sed. Petrology, v. 4, p. 65–77.

Krumbein, W. C., 1937, Sediments and exponential curves: Jour. Geol., v. 45, p. 577–601.

Krumbein, W. C., 1938, Size frequency distributions of the sediments and the normal phi curve: Jour. Sed. Petrology, v. 8, p. 84–90.

Norrman J. O., 1970, Trends in postvolcanic development of Surtsey Island. Progress report on geomorphological activities in 1968: Surtsey Res. Prog. Rept., v. 5, The Surtsey Research Society, Reykjavík, p. 95–112.

Visher, G. S., 1969, Grain size distributions and depositional processes: Jour. Sed. Petrology, v. 39, p. 1074–1106.

The Opaque Mineralogy of Surtsey

By
SIGURDUR STEINTHÓRSSON
Division of Geosciences, Science Institute, University of Iceland

The opaque mineralogy of the Surtsey rocks is of interest because it affords insight into the relationship between volcanic gases and the magma from which they exsolved. Furthermore, in a general way changes in the oxidation state of the cooling melt and rock are reflected in the oxide minerals.

In the following the minerals will be briefly described, some analyses reported, and conclusions drawn.

Earlier work on the opaque minerals in Surtsey is scant. From modal analyses of samples representing different degrees of crystallisation Steinthórsson (1966) found that a small percentage (0.4—0.8) of "opaques" was consistently present in the rock, remaining at that low level until more than 60% of the melt had crystallised. Then the percentage started to grow, increasing with degree of crystallisation to about 10% in fully crystalline samples. Jakobsson 1968, 1969) briefly described the ore minerals in some samples from the Vestmann Islands (including Surtsey). According to him the ores consist of magnetite, ilmenite and chrome-spinel, and may reach 12% by volume. Chrome-spinel occurs included in olivine, and when present in the groundmass it is heavily zoned towards magnetite. A preliminary microprobe analysis revealed 35—40% of hercynite in the chromite.

OPTICAL OBSERVATIONS

The four samples inspected optically are described below. They are listed in Table I.

TABLE I
Samples inspected.

SU 32	First lava, flowed April 1964, about 1 m below surface of flow. Coll. S. Jakobsson, August 1964. For analysis, see Steinthórsson (1966).
SU 11	Lava, flowed April—May 1965. Coll. S. Jakobsson.
SU 18	Lava, flowed August 1966, from surface of flow. Coll. S. Jakobsson.
1242	Bomb from Jólnir (August 1966). Coll. B. Johnsen.

In sample SU 32 opaques amount to some 5%. *Titanomagnetite* is dominant. The crystals tend to be equidimensional xenomorphic and frequently skeletal, 0.05—0.1 mm in diameter. They are homogeneous, showing no oxyexsolution. *Ilmenite* crystals constitute less than 10% af the opaques. The grains are frequently skeletal and tend to be acicular in shape. Comparatively large grains measure 0.7x0.001 or 0.002 mm. *Chrome-spinel* is only found included in olivine. Grains situated near the crystal margin or on cracks are zoned towards titanomagnetite. The crystals show equidimensional cubic form, less than 0.025 mm in diameter (Plate I, a).

SU 11: Opaques estimated about 5%. *Titanomagnetite* dominates. The grains are less than 0.1 mm in diameter, xenomorphic, showing pronounced skeletal texture. Oxyexsolution of ilmenite is quite pronounced (Plate I, b). *Ilmenite* occurs both as discreet acicular crystals (< 10% of opaques) and as the product of exsolution in the titanomagnetite. *Chromite* only occurs included in olivine phenocrysts, where it frequently shows zoning in colour from dark grey to

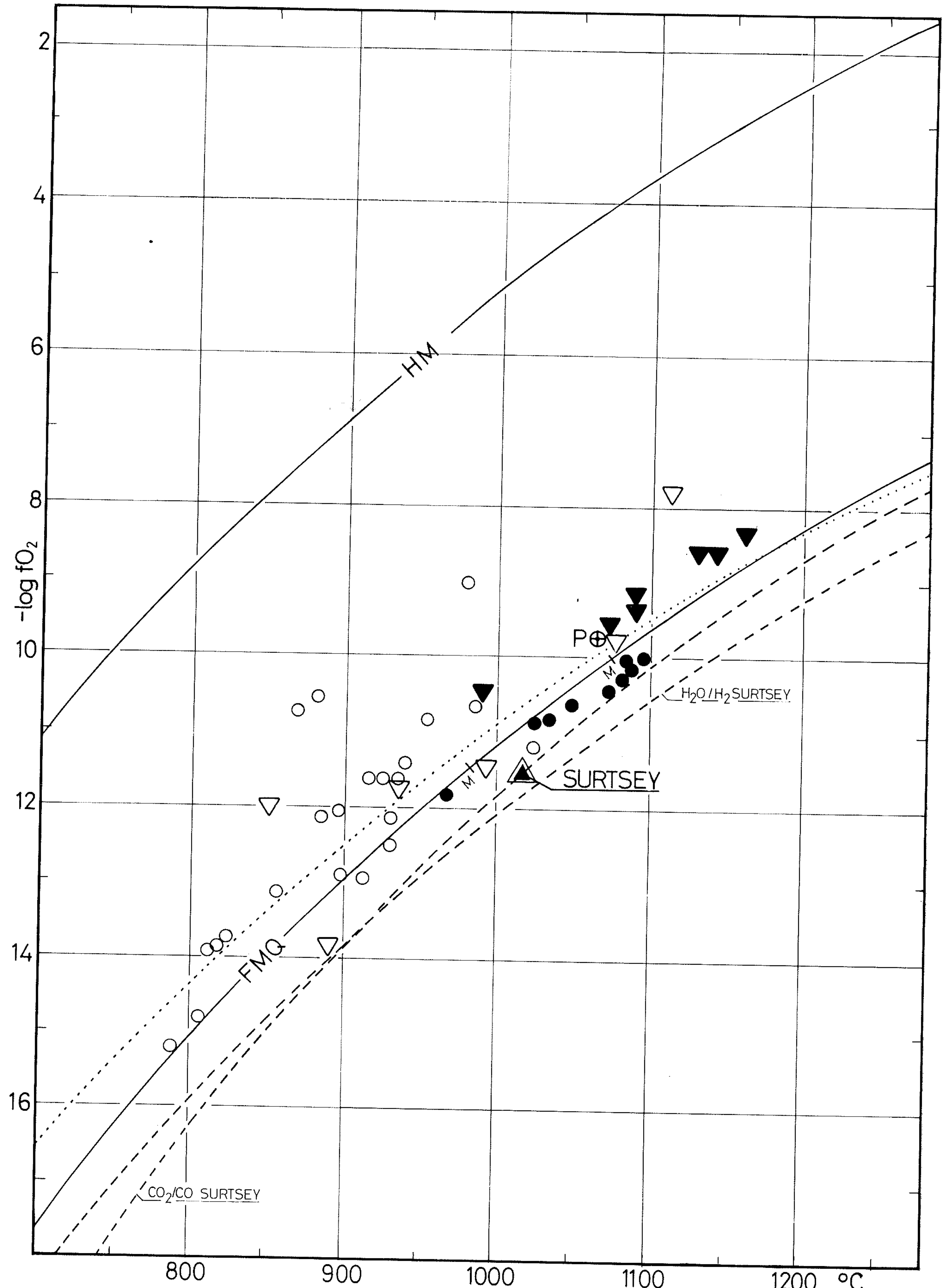
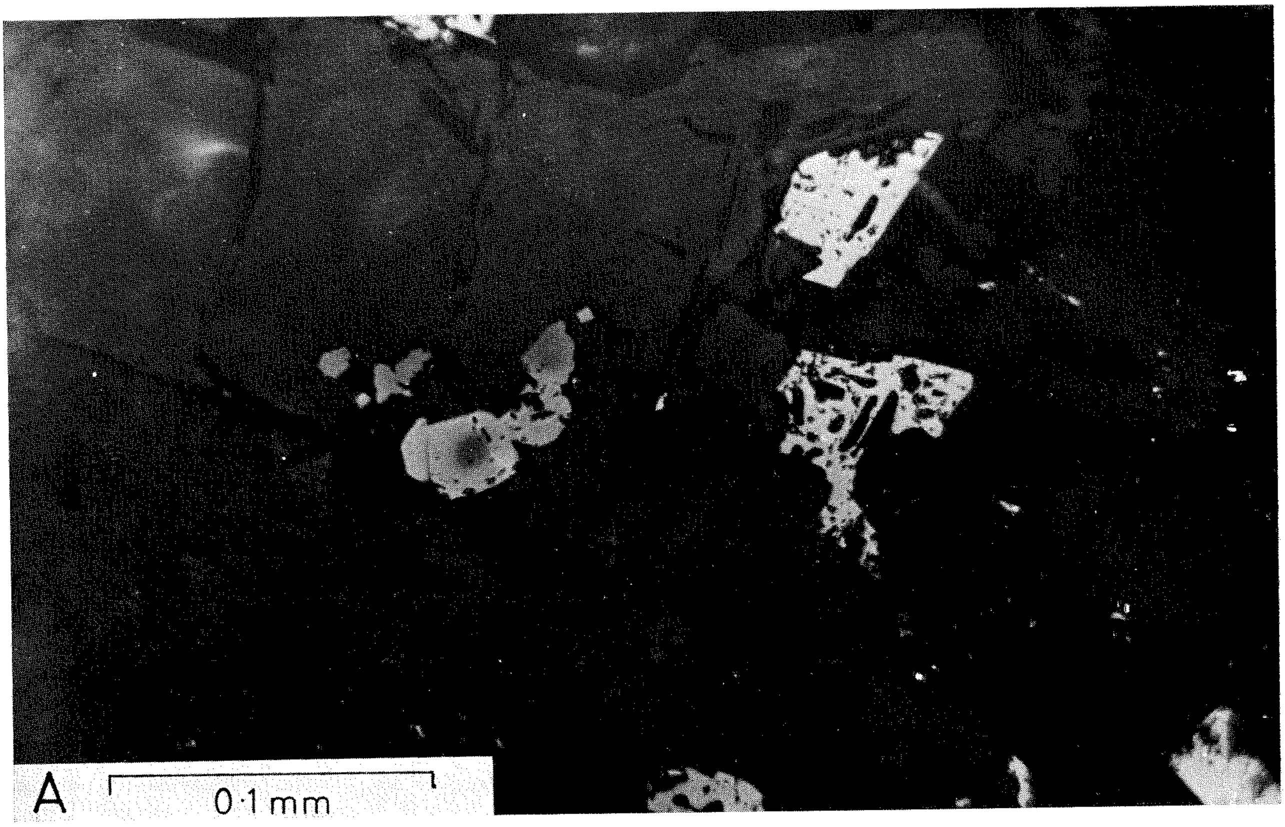


Fig. 1. Oxygen fugacities (-log fo_2) plotted against temperature showing the relationship between fo_2, calculated from an analysis of volcanic gas from Surtsey *(dashed curves)*, and that obtained from the analysis of Fe-Ti oxides in the lava (trinagle). The buffer assemblages HM and FMQ are plotted for reference. *Dotted curve:* volcanic gas from Hawaii (Heald et al., 1963). *Circle P:* a direct measurement in Kilauea lava lake, Hawaii (Peck & Wright, 1966). *Curve M—M:* the curve followed during the cooling of the Makaopuhi lava lake (from Fe-Ti oxide analyses, Evans & Moore, 1968). *Filled circles* and *inverted triangles:* basaltic lavas, respectively, from E. Iceland and elsewhere (Carmicael & Nicholls, 1967) and from Tristan da Cunha (Anderson, 1968). *Open circles* and *inverted triangles:* acid and intermediate volcanics, as above (Carmichael & Nicholls, 1967, and Anderson, 1968).



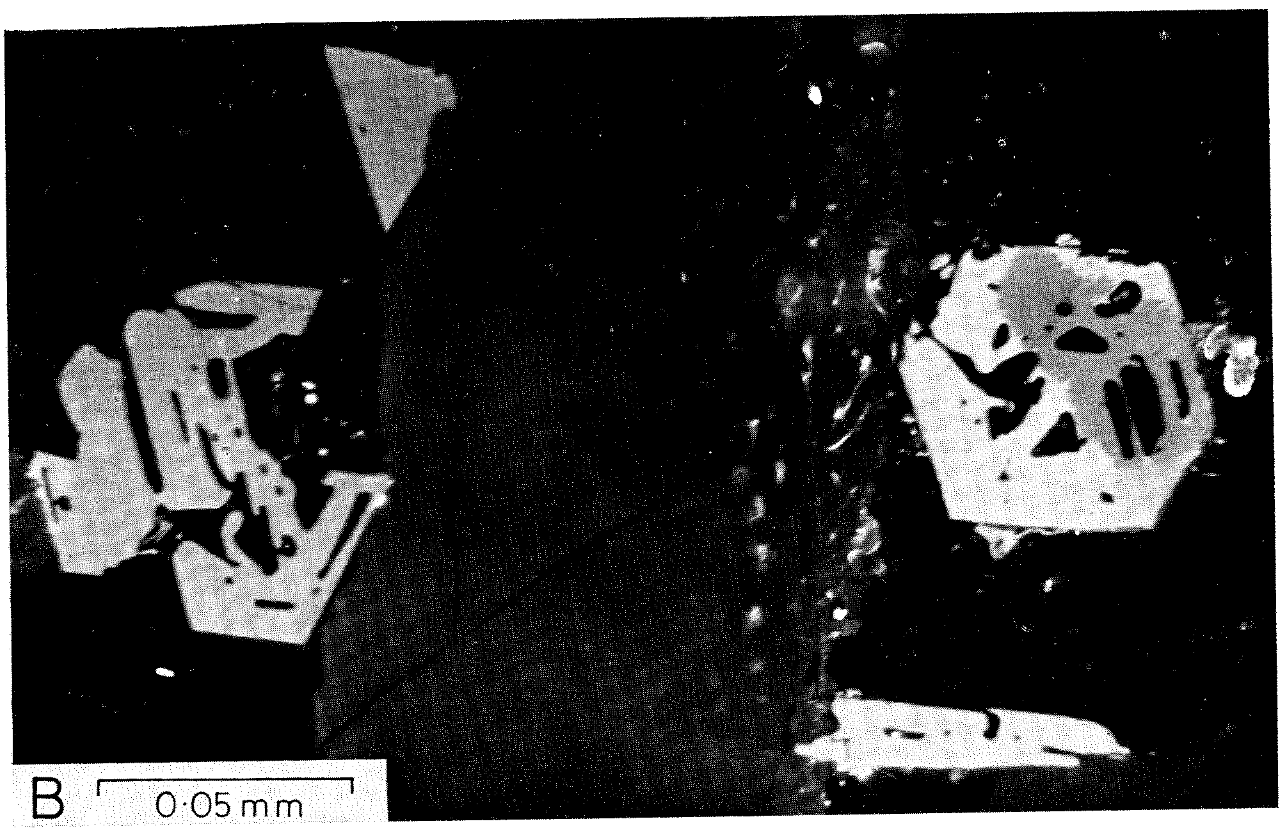
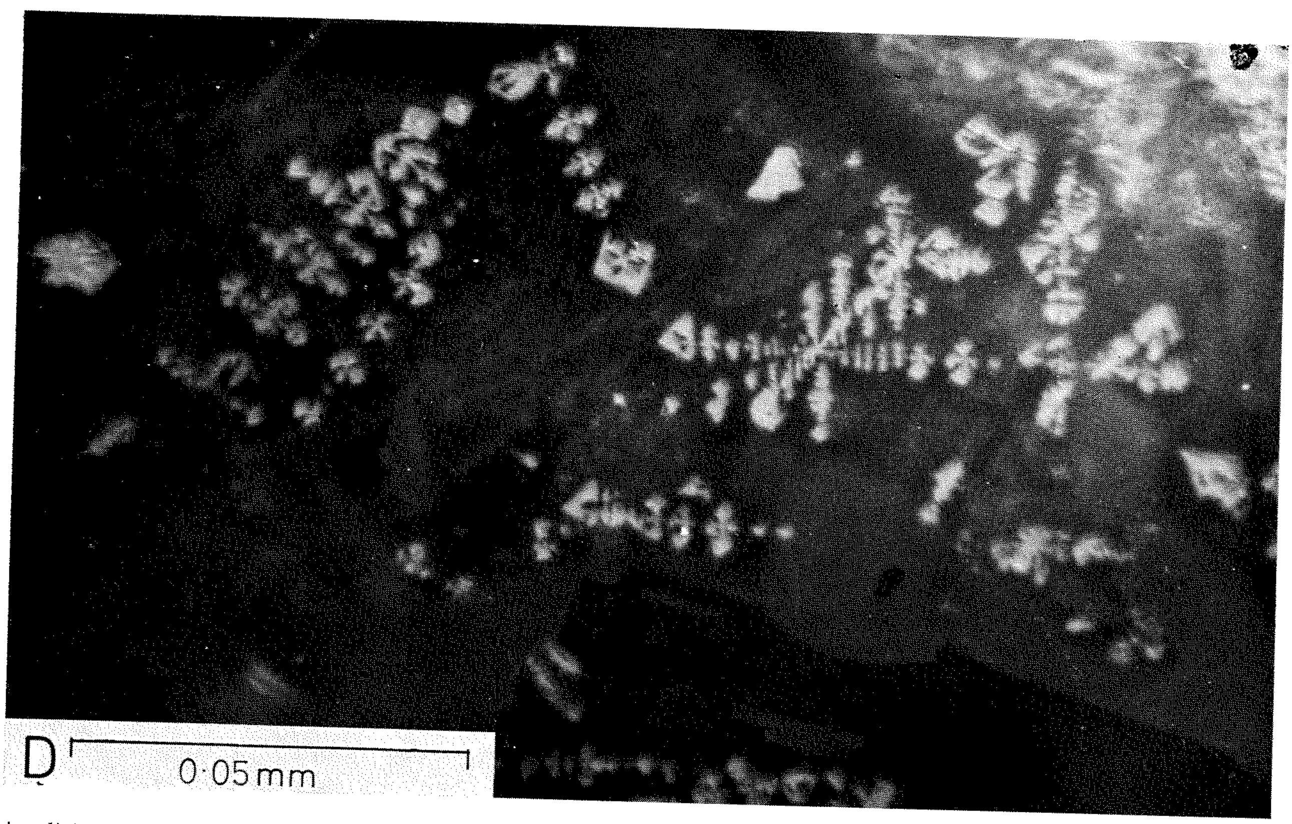


Plate 1. All the photographs are taken using a x25 oil-immersion objective and plane polarised light. A) Chrome-spinel included in olivine has a thick rim of titanomagnetite. Unexsolved xenomorphic and skeletal titanomagnetite in the groundmass (sample SU 32). B) Skeletal titanomagnetite showing exsolution of ilmenite (SU 11). C) Grains of chrome-spinel included



in olivine and showing zoning to titanomagnetite. Tiny grains of skeletal titanomagnetite in groundmass (surface of lava, Búdahraun, Snaefellsnes). D) Skeletal titanomagnetite at surface of lava, as in SU 18. (Present photograph of Búdahraun, Snaefellsnes.)

lighter grey at the margin. This may reflect substitution of Al for Cr in the structure. One *sulphide* crystal (pyrite?) was observed associated with chromite.

SU 18: Opaques constitute less than 1%. *Chromite* is mostly associated with the olivine as inclusions, but is also found in the glassy groundmass. The largest chromite crystal was observed in the groundmass and measured 0.1x0.05 mm. A very thin veneer of lighter grey or yellowish was observed on some of the chromite crystals. *Titanomagnetite* occurs in tiny skeletal forms all over the groundmass, presumably lending the dark colour and opacity to the sideromelane at the lava surface (Plate I, d).

1242: Tiny crystals (d = 0.02 mm) of *chromite* occur both within olivine phenocrysts and without. The groundmass is sideromelane glass which is quite opaque, but shows red internal reflections – probably due to haematite.

These samples represent four different degrees of crystallisation ond oxidation. The latter is of twofold nature: (a) Progressive oxidation takes place in the crystallising melt due to the buildup of volatile concentration and the selective removal of ferrous iron into olivine and pyroxene, and (b) the sample is oxidised due to exposure to the atmosphere (SU 18, 1242).

The least crystalline state is represented by sample 1242, in which chromite occurs in the glass. In sample SU 18 it is suggested that the crystallisation is slightly more advanced, with a hercynite-richer composition forming on the margin of the Cr-spinel (cf. Evans & Moore, 1968, pp. 103–104). Sample SU 32 is crystalline, but the titanomagnetite is homogenous and unoxidised. Only Cr-spinel protected within olivine phenocrysts (analysis 6 in Table II) has survived the peritectic reaction with augite (cf. Irvine, 1967, p. 76). Finally, in SU 11 the titanomagnetite shows subsolidus oxidation with the exsolution of ilmenite.

The sequence of crystallisation in a basaltic melt is dependent of the oxidation state. In particular, low oxidation state (high FeO/Fe_2O_3 ratio) favours the early formation of olivine, whereas high oxidation state brings about the crystallisation of titanomagnetite. Cr is very insoluble in basaltic melts (cf. Irvine, 1967, p. 72), and if present chromite will be the first mineral to form at normal oxygen pressures. From the mineralogy of the samples it is evident that chrome-spinel was the first mineral to crystallise, closely followed by olivine in which it is included. The iron-titanium oxides crystallised last. Apparently there was a hiatus in the crystallisation of the oxides after the initial formation of the chromite, until the activity of ferric iron in the melt was high enough to stabilise titanomagnetite. The available chromite reacted with the liquid and disappeared.

TABLE II

Electron microprobe analyses of coexisting titanomagnetite and haemoilmenites (1–5) and one chrome-spinel (6) from Surtsey dolerite sample 1088. The mineral compositions are recalculated according to the methods of Carmichael (1967) (C) and Anderson (1968) (A).

	1	2	3	4	5	6
FeO	53.40	53.48	42.87	42.29	43.52	15.10
Fe_2O_3	13.88	13.23	4.03	4.33	2.51	3.60
TiO_2	26.98	27.39	50.48	50.44	51.50	0.67
Al_2O_3	3.92	3.14	0.09	0.05	0.20	39.76
MgO	1.83	1.74	0.84	1.10	0.91	15.74
MnO	0.87	0.85	1.01	1.09	1.15	0.17
Cr_2O_3	0.03	0.04	0.02	0.01	0.05	25.06
CaO	–	–	–	–	–	0.04
SiO_2	–	–	–	–	–	0.29
Total	100.91	99.88	99.34	99.31	99.84	100.43

C) $Usp_{79}Mt_{21}$ $Usp_{80}Mt_{20}$ Hm_4Im_{96} Hm_4Im_{96} Hm_3Im_{97}
A) $Usp_{76}Mt_{24}$ $Usp_{78}Mt_{22}$ Hm_4Im_{96} Hm_5Im_{95} Hm_3Im_{97}

TABLE III

°K	K_w	log fo_2 from eq. 1	K_c	log fo_2 from eq. 1
1000	–10.07	–17.60	–10.22	–18.14
1100	– 8.89	–15.24	– 8.88	–15.46
1200	– 7.90	–13.26	– 7.77	–13.24
1300	– 7.07	–11.60	– 6.82	–11.34
1400	– 6.35	–10.16	– 6.02	– 9.74
1500	– 5.73	– 8.92	– 5.32	– 8.34
1600	– 5.18	– 7.72	– 4.71	– 7.12
1700	– 4.70	– 6.86	– 4.17	– 6.04

Equilibrium constants K_w (eq. 1) and K_c (eq. 2), calculated on the basis of data in the JANAF Tables (1965, 1966), (from H. D. Holland, 1970, unpublished) and oxygen fugacities calculated from a gas analysis from Surtsey: H_2O = 86.13, H_2 = 4.58, CO_2 = 5.54, CO = 0.39 (Febr. 21, 1965, Sigvaldason & Elísson, 1968).

CHEMISTRY

Coexisting titanomagnetite and haemoilmenite were analysed in one sample with the electron microprobe (for description of sample 1088, see Steinthórsson, 1966). The sample is of well-crystallised ophitic dolerite, in which the titanomagnetite shows abundant exsolution. The analyses are reported in Table II. They have been recalculated according to the method of Carmichael (1967), whereas the composition of the minerals was recalculated both as described by Carmichael (1967) and Anderson (1968). Applying the composition $Usp_{77}Mt_{23}$ and Hm_4Im_{96} to the curves of Lindsley (Buddington & Lindsley, 1964) the temperature and fo_2 of last equilibration is obtained: $T = 1020°C$, $\log fo_2 = -11.5$. This point is plotted as a triangle in fig. 1.

These results may be compared with those obtained from the analyses of volcanic gases in Surtsey, reported by Sigvaldason & Elísson (1968). The fo_2 of the gas is calculated from the ratios H_2/H_2O and CO/CO_2, which are governed by the reactions

$$(1)\ H_2O = H_2 + \tfrac{1}{2}O_2\ ;\ K_w = \frac{[H_2]}{[H_2O]} \cdot fo_2^{\frac{1}{2}}$$

$$(2)\ CO_2 = CO + \tfrac{1}{2}O_2\ ;\ K_c = \frac{[CO]}{[CO_2]} \cdot fo_2^{\frac{1}{2}}$$

In Table III are listed the values of the two equilibrium constants at various temperatures, and the corresponding fo_2's. The $fo_2 - T$ curves are plotted in fig. 1.

The two curves intersect at $T = 900°C$, $\log fo_2 = -14$ atm. Taking these numbers at face value the gases equilibrated down to 900°C whereas the oxide minerals in this particular lava-sample stopped reacting at 1020°C. There is, however, an excellent agreement between the gas-analyses and the results obtained from the oxide minerals. The Surtsey magma, accordingly, was rather more reducing than basalts hitherto reported, as seen in fig. 1, where the results of Carmichael & Nicholls (1967) and Anderson (1968) for basaltic rocks are plotted.

ACKNOWLEDGEMENTS

The author is indebted to Mr. S. Jakobsson for the polished samples, and to Mr. N. Óskarsson for preparing the diagram. The analyses were performed on the eloctron microprobe in Princeton University, Princeton, N.J.

References:

Anderson, A. T. (1968): The oxygen fugacity of alkaline basalt and related magma, Tristan da Cunha. Am. J. Sci. *266*, 704–727.

Buddington, A. F. & D. H. Lindsley (1964): Iron-titanium oxide minerals and synthetic equivalents. J. Petrology *5*, 310–357.

Carmichael, I. S. E. (1967): The iron-titanium oxides of salic volcanic rocks and their associated ferromagnesian silicates. Contr. Mineral. and Petrol. *14*, 36–64.

Carmichael, I. S. E. & J. Nicholls (1967): Iron-titanium oxides and oxygen fugacities in volcanic rocks. Jour. Geophys. Res. *72*, 4665–4687.

Evans, B. W. & J. G. Moore (1968): Mineralogy as a function of depth in the prehistoric Makaopuhi tholeiitic lava lake, Hawaii. Contr. Mineral. and Petrol. *17*, 85–115.

Heald, E. F., J. J. Naughton & I. L. Barnes (1963): The chemistry of volcanic gases, 2. Use of equilibrium calculations in the interpretation of volcanic gas samples. J. Geophys. Res. *68*, 545–557.

Holland, H. D. (1970): Unpublished manuscript on geochemistry.

Irvine, T. N. (1967): Chromian spinel as a petrogenetic indicator. Part 2. Petrologic applications. Canad. J. Earth Sci. *4*, 71–103.

Jakobsson, S. (1968): The geology and petrography of the Vestmann Islands. A preliminary report. Surtsey Research Progress Report *IV*, 113–130.

Jakobsson, S. (1969): Vestmannaöerne. En beskrivelse af bjergarternes mineralogi. (Manuscript, 23 pp.).

JANAF, Thermochemical Tables, 1965. U.S. Dept. of Commerce, National Bureau of Standards, Inst. for Applied Technology. P Bs. 168 370.

JANAF, Thermochemical Tables, 1966. First addendum. U.S. Dept. of Commerce, National Bureau of Standards, Inst. for Applied Technology, P Bs. 168 370–1.

Peck, D. L., and T. L. Wright (1966): Experimental studies of molten basalt in situ: A summary of physical and chemical measurements on Recent lava lakes of Kilauea volcano, Hawaii. (abs.) Geol. Soc. Am. 1968 Ann. Meeting Abst. 158–159.

Sigvaldason, G. E. & G. Elísson (1968): Collection and analysis of volcanic gases at Surtsey, Iceland. Geochim. Cosmochim. Acta *32*, 797–805.

Steinthórsson, S. (1966): Surtsey: Petrography and chemistry. Surtsey Research Progress Report *II*, 77–86.

Precision Levelling in Surtsey

By
EYSTEINN TRYGGVASON
University of Tulsa, Tulsa, Oklahoma

INTRODUCTION

In late June 1967 a levelling profile was established across the lava of Surtsey. This profile consisted of 42 bench marks and was about 2060 meters long. This profile has been levelled five times, in June 1967, August 1967, June 1968, July 1969 and June 1970. In June 1968 the profile was surveyed to determine the location of each bench mark (Tryggvason 1970). During each levelling an attempt has been made to determine the sea level elevation. The repeated levellings of the Surtsey profile show that the lava of Surtsey has been subsiding continuously between 1967 and 1970. The rate of subsidence has been decreasing continuously during the same period. The maximum subsidence has been observed near the center of the island where the rate was more than one millimeter per day in 1967 (Tryggvason 1968).

RATE OF DEFORMATION OF THE SURTSEY LAVA

The repeated levellings in Surtsey allow determination of the vertical component of ground deformation between any two levellings.

The levellings provide the elevation differences between any pair of bench marks (Figure 1). The vertical component of ground deformation between two levellings is the change in the measured elevation difference.

During one levelling at time t_1 the elevation of bench mark A is H_{A1} and that of bench mark B is H_{B1}. At another levelling at time t_2 the elevation of these same bench marks are H_{A2} and H_{B2}. The difference in elevation of these two bench marks are:

$$DH_{AB1} = H_{B1} - H_{A1}$$

and

$$DH_{AB2} = H_{B2} - H_{A2}$$

The vertical component of deformation between bench marks A and B during the time interval t_1 to t_2 is:

$$V_{AB12} = DH_{AB2} - DH_{AB1}$$

and the rate of deformation is:

$$R_{AB12} = \frac{V_{AB12}}{t_2 - t_1} =$$

The vertical component of deformation, as defined above can be a ground tilt or a more complicated deformation. If the horizontal distance between the two bench marks is short, the observed deformation can be interpreted as one component of ground tilt. However, the deformation observed in Surtsey (Figure 2) varies rapidly along the profile, so a linear tilt cannot be expected between any two bench marks.

Figure 2 shows the deformation between bench mark 601 on the east coast of Surtsey and each of the other bench marks of the Surtsey. All the bench marks have subsided relative to 601 and the rate of subsidence has decreased by a factor of approximately two each year. Thus the subsidence of bench mark 625 relative to 601 was 32.2 cm during the first year between June 1967 and June 1968, 17.0 cm during the second year and 7.7 cm during the third year. If the deformation between two bench marks a short distance

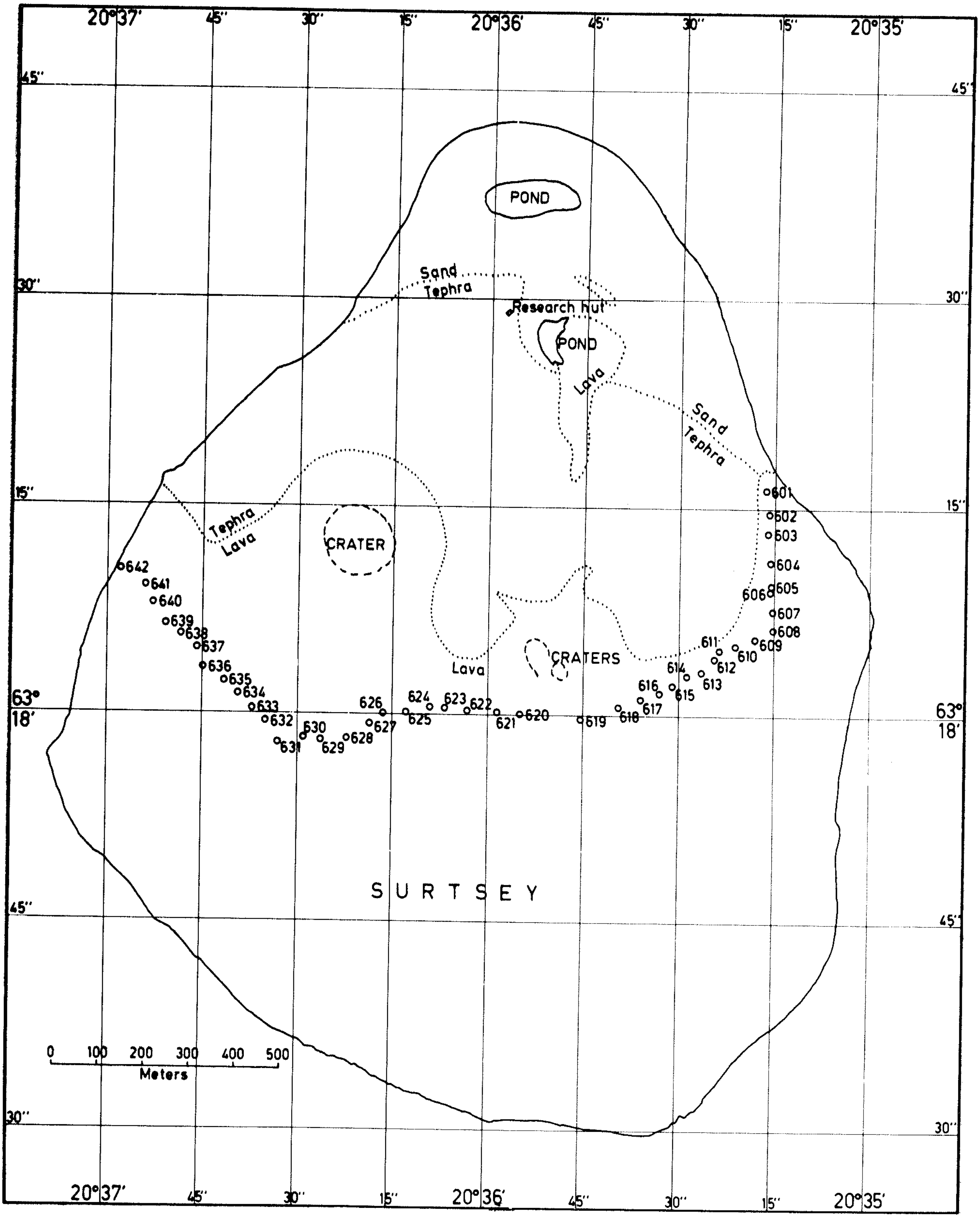


Fig. 1. Map of Surtsey showing location of the levelling profile.

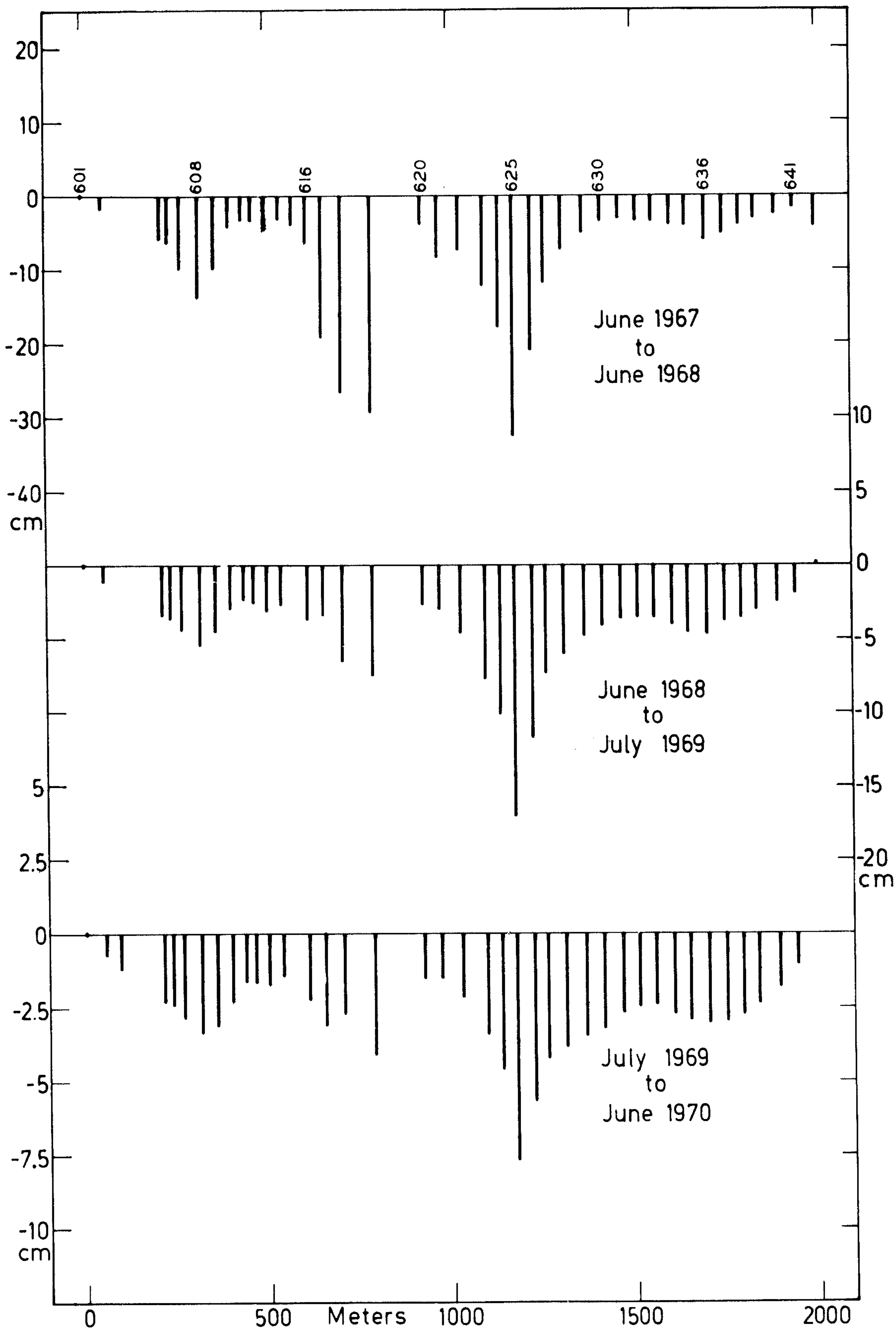


Fig. 2. Annual rate of subsidence of the Surtsey bench marks relative to 601 on the east shore of the island. The vertical scale is changed by a factor of two each year to show more clearly that the subsidence rate is slowing down by a factor of approximately two every year.

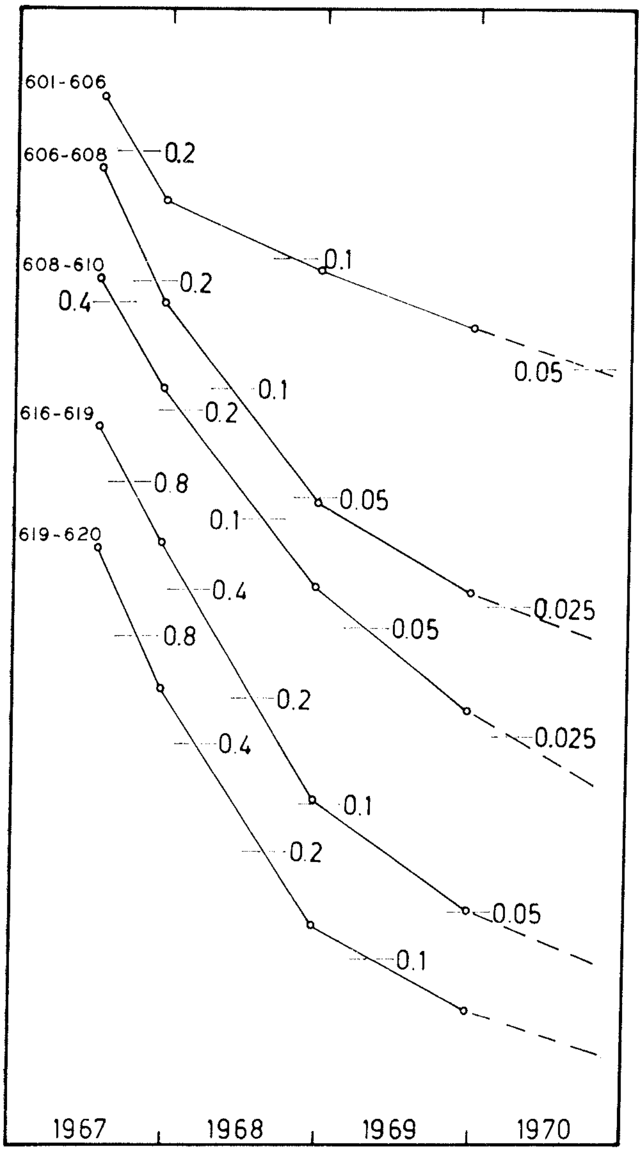


Fig. 3. Rate of deformation as a function of time for selected bench mark intervals on the eastern half of the levelling profile. The rate is given in millimeters per day with separate scale for each curve.

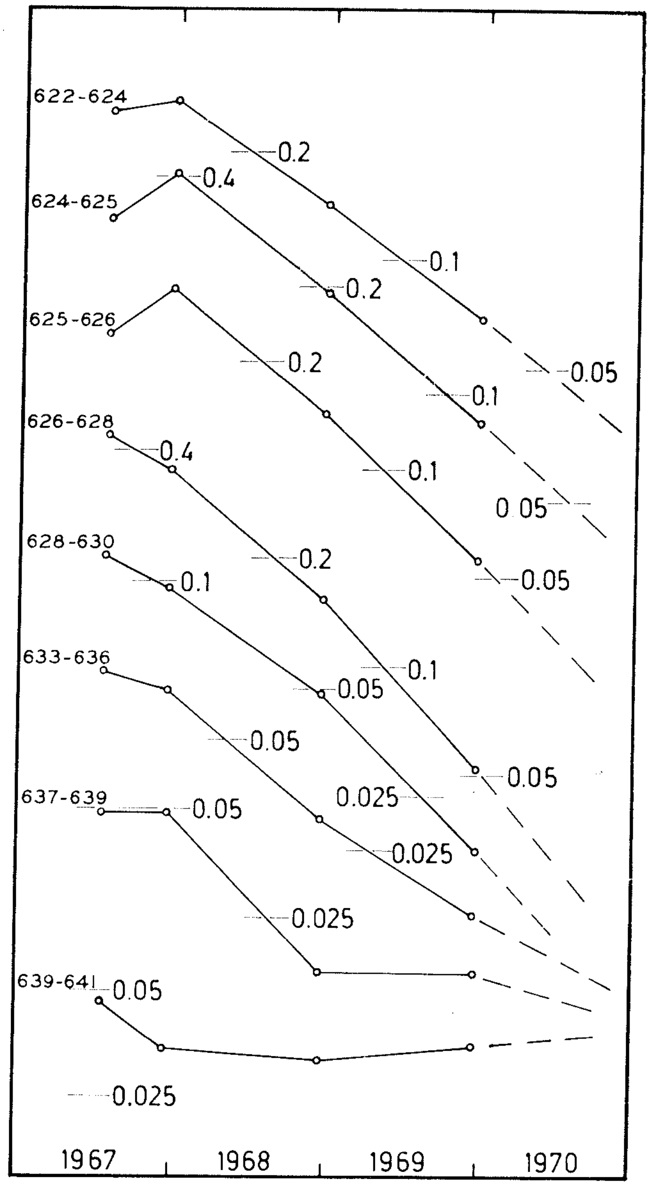


Fig. 4. Rate of deformation as a function of time for selected bench mark intervals on the western half of Surtsey. The convex shape of the curves is strikingly different from the same type of curves in Fig. 3 for the eastern half of the island.

apart is studied, it is evident that the rate of decrease in the deformation is different for different parts of the profile. On the eastern part of the profile (between bench barks 601 and 620) the deformation rate decreased more rapidly during the first part of the observation period than later (Figure 3) so curves showing the logarithm of the deformation rate versus time are concave, while on large portion of the western half of the profile this pattern is differnt so the same type of curves are convex (Figure 4). Near the west coast of Surtsey between bench marks 639 and 641 the deformation rate has been nearly constant during the 3 years of observation.

This rather irregular trend in the rate of deformation of the Surtsey lava surface makes it difficult to predict with any accuracy how much deformation will take place during the coming years or when this deformation will come to an end. However, the rapidly decreasing rate of deformation indicates that the total subsidence after the 1970 levelling, relative to bench mark 601, will not exceed 10 centimeters for any point on the levelling profile.

Figure 5 shows a rough estimate of the subsidence rate relative to bench mark 601 along the Surtsey profile in the year 1973 assuming a continuation of the observed change in the subsidence rate during the three years, 1970 to 1973. This prediction indicates that the peak in subsidence rate between bench marks 616 and 620 has completely disappeared in 1973.

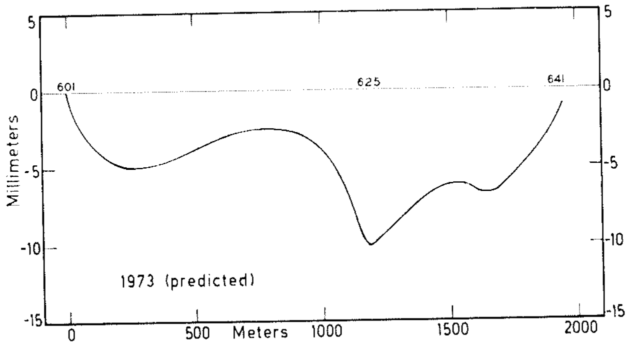


Fig. 5. Estimated annual rate of subsidence of the Surtsey profile in 1973 relative to bench mark 601. The horizontal scale is distance along the profile, the same as on Fg. 2.

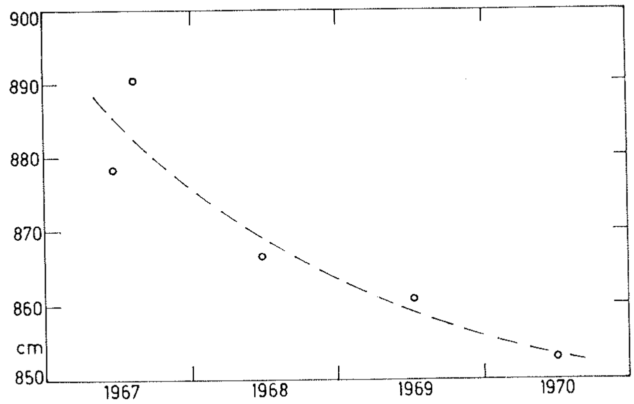


Fig. 6. Elevation of bench mark 601 above the surface of the pond "Dropi" or above ground water table at the pond site. The elevation given is very near the mean sea level elevation. The smooth curve is an estimate of the variation of elevation of 601 above mean sea level.

SUBSIDENCE OF SURTSEY

In 1967 and 1968 a lake (Dropi) existed on Surtsey north of the steep slopes of the principal craters. This lake had a very constant elevation during the days of the levelling work. In 1967 the elevation of this lake was compared with the elevation of a tidal pond near the north shore of Surtsey, and the surface elevation of the lake Dropi was found to be very close to mean sea level, probably about 10 centimeters above average sea level.

In 1969 and 1970 the lake Dropi had disappeared. However, the ground water table was close to the surface and small wells were dug to observe the water table.

Figure 6 shows the elevation of bench mark 601 above the surface of the lake Dropi (in 1967 and 1968) and above the ground water table at the site of the lake (in 1969 and 1970).

As the surface of the lake was very close to mean sea level in 1967, it is assumed that the water table in 1968 through 1970 at the site of the lake was also very near mean sea level. Therefore the elevation values on Figure 6 give the elevation of bench mark 601 above mean sea level, with an accuracy of approximately 10 centimeters.

It is clear from these measurements that bench mark 601 has been subsiding relative to mean sea level. The rate of subsidence is slowing down by a factor of approximately 2 each year. The rate of subsidence was probably 15 to 20 cm per year in 1967—68 but has slowed down to roughly 5 cm per year in 1969—70, resulting in a total subsidence of 30 to 40 centimeters between 1967 and 1970. In the discussion of the deformation of the lava surface on Surtsey, the subsidence of each bench mark relative to 601 was given. To obtain the absolute subsidence of each bench mark the subsidence of bench mark 601 has to be added to the relative subsidence.

ACKNOWLEDGEMENTS

This research was supported by National Foundation grants GP-5365, GA-987, and GA-4112, and by the Surtsey Research Society.

References:

Tryggvason, E., (1968): Result of Precision Levelling in Surtsey, Surtsey Research Progress Report IV, pp 149—158.

Tryggvason, E., (1970): Precision Levelling on Surtsey in 1968, Surtsey Research Progress Report V, pp 113—116.

GEOCHEMISTRY

Hydrocarbons and Acids of Hekla Volcanic Ash

PAT HAUG
Geochemisches Institut, der Universität Göttingen
and
JULIA SEVER
Department of Chemistry, Louisiana State University, Baton Rouge, Louisiana

INTRODUCTION

Organic matter found on the surface of the earth is probably derived from once living organisms. Fatty acids and hydrocarbons occur in nature (HILDITCH and WILLIAMS, 1964) and have been identified in both recent and ancient sediments (ABELSON and PARKER, 1962; BLUMER and COOPER, 1967; COOPER, 1962). Hydrocarbons are minor but ubiquitous components of all organisms, occur extensively in older sediments, and are among the most stable organic molecules (JOHNS *et al.*, 1966 and MEINSCHEIN, 1969). Freshly fallen ash taken from the erupting volcano, Hekla, southwest Iceland was examined to determine if organic matter was present. A chemical scheme designed for extraction and separation of both hydrocarbons and fatty acids was used.

EXPERIMENTAL

On June 16, 1970, 350 grams of hot, two-inch diameter pieces of volcanic ash were collected in sterile Mason jars which constituted Sample I. On June 28, 1970 ash was collected, wrapped in aluminium foil and sealed in a polyethylene bag constituting Sample II. A volcanic bomb was found, the interior of which constituted Sample III (HAUG, 1971). Carbon analysis of Hekla fine tephra and a bomb interior were reported as 144 and 72 ppm respectively (MOORE, 1971). Previously reported, a sample from Syrtlingur containing 50—100 ppm total organic carbon showed no detectable aliphatic hydrocarbons (PONNAMPERUMA *et al.*, 1967). However, aspartic acid, alanine as well as traces of glycine and serine were observed.

To ensure the removal of contamination from the outer surfaces, the samples were boiled in methanol prior to crushing. The methanol was taken to dryness and treated as a lipid extract in order to determine what hydrocarbons and fatty acids were present as surface contamination. The samples were crushed in a jaw crusher and passed through a laboratory hammer mill for finer grinding. Precautions were taken at this point to reduce possibilities for contamination by thoroughly cleaning the crushing tools before and after each sample was crushed. Sample I was extracted for eight days in a Soxhlet thimble with 500 ml of chloroform. Samples II and III were extracted with 500 ml of chloroform for one hour using ultrasonic vibrations. Each sample was thereafter treated by identical methods. The samples were filtered after extraction and the chloroform extract taken to dryness on a rotary evaporator. The lipid residue was weighed and then saponified using 0.05 N potassium hydroxide in methanol for two hours with gentle refluxing. The nonsaponifiable fraction containing the hydrocarbons was separated from the saponifiable fatty acid fraction by multiple extraction of the alkaline solution with benzene. The saponifiable alkaline fraction was then acidified with hydrochloric acid to pH 3 and extracted with benzene to remove the fatty acids from solution. The saponifiable and nonsaponifiable fractions were taken to dryness and weighed. The nonsaponifiable fraction was taken up in one ml of hexane, placed on a chromatographic column packed with prewashed silica gel and silicic acid (1:1, v/v) (Woelm, Activity I). The aliphatic hydrocarbons were eluted with 100 ml of hexane. The hexane fraction was dried on a rotary evaporator. This hydrocarbon fraction was weighed

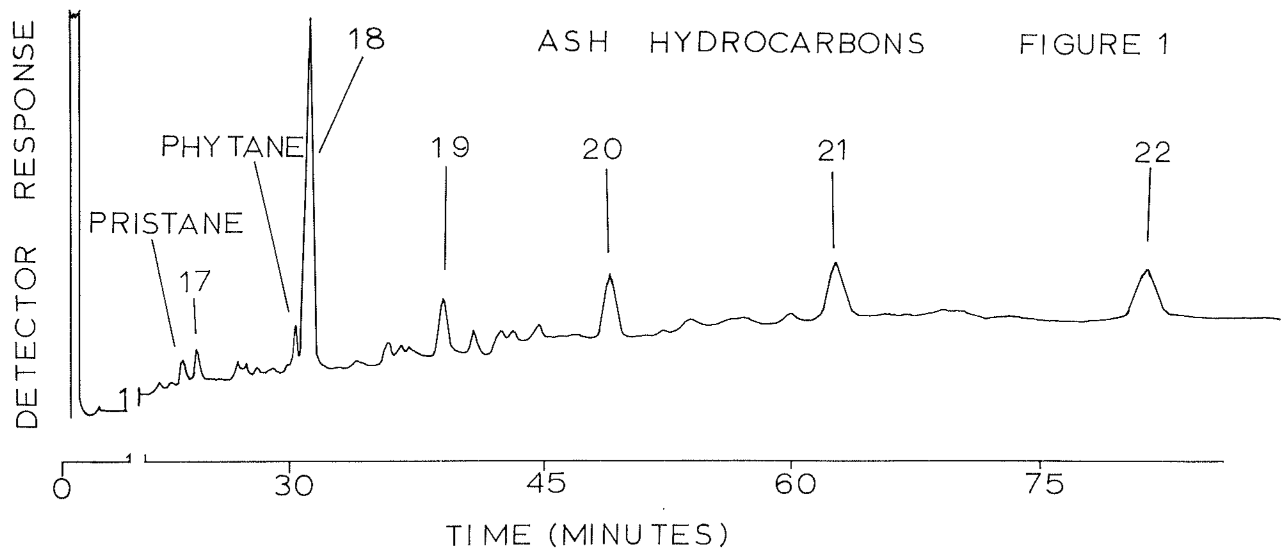


Fig. 1. Gas chromatogram of alkanes from ash. Stainless steel capillary column (150 feet × 0.02 inches i.d.) coated with Apiezon L. Barber Coleman (Series 5000) gas chromatograph with helium flow of six ml/min using split. Temperature programmed from 150°C to 230°C at 3°C/min.

and used for identification by means of gas-liquid chromatography. The fatty acid fraction was taken to dryness and methylated using BF_3-MeOH reagent. The fatty acid methyl ester fraction was weighed and used for identification by means of gas-liquid chromatography.

All solvents used in the chemical analyses were reagent grade and were distilled before use. Distilled water was used throughout the isolation process. As a check on contamination of samples, all solvents were treated as samples and were run through the isolation schemes for separation of hydrocarbons and fatty acids. Using the same sensitivity on the GLC at which the samples were run, the only contaminants detected were low molecular weight hyrocarbons which did not interfere with those isolated from the samples. A blank was run on the Soxhlet thimble. Detectable amounts of hydrocarbons including pristane and phytane were observed. This accounts for a large portion of the hydrocarbons identified in Sample I.

RESULTS

Normal, saturated hydrocarbons ranging from C_{16} to C_{23} having a bimodal distribution with maximums at C_{18} and C_{22} (Figure 1) were detected in each sample of ash examined. Living organisms, particularly non-marine, exhibit an odd-carbon number predominance in their hydrocarbon constituents; however, there was no odd/even predominance in the hydrocarbons in the ash. Isoprenoids, pristane and phytane were detected. Usually the presence of these hydrocarbons is cited as evidence of biological activity. The hydrocarbon distribution of all three samples and the MeOH wash was qualitiatively the same. Sample I, however, contained a much higher percentage of octadecane than did the other two samples. This was not observed in the thimble extractions. Sample III contained an anomalous peak in the C_{26} region believed to be an ester since this fraction was not saponifiable. It is interesting to note that the hydrocarbon fraction of the Diablo meteorite analyzed by Ponnamperuma also contained a prominent saturated C_{18} hydrocarbon (PONNAMPERUMA, 1971).

The fatty acids extracted from each ash sample ranged from $C_{12:0}$ to $C_{16:0}$; $C_{18:1}$ represented 40 percent of the fatty acid fraction. Again, all samples were qualitiatively the same (Figure 2). The total fatty acid fractions in Samples II and III represented less than two ppm.

One would not expect to find organic remnants in fresh volcanic ashes since the high temperatures would have destroyed any organic matter which might have been present. Since both hydrocarbon and fatty acids in all samples were just above contamination level, it cannot be said with certainty that these organic components were indigenous to the ash. The porous ash provides large surface areas for absorption of organic material from air, a possible source of contamination. This hypothesis is supported by the fact that both the acids and the hydrocarbons of each sample was qualitatively similar to the MeOH wash acids and hydrocarbons. As would be expected the hydrocarbons and acids are present in concentrations of less than two ppm.

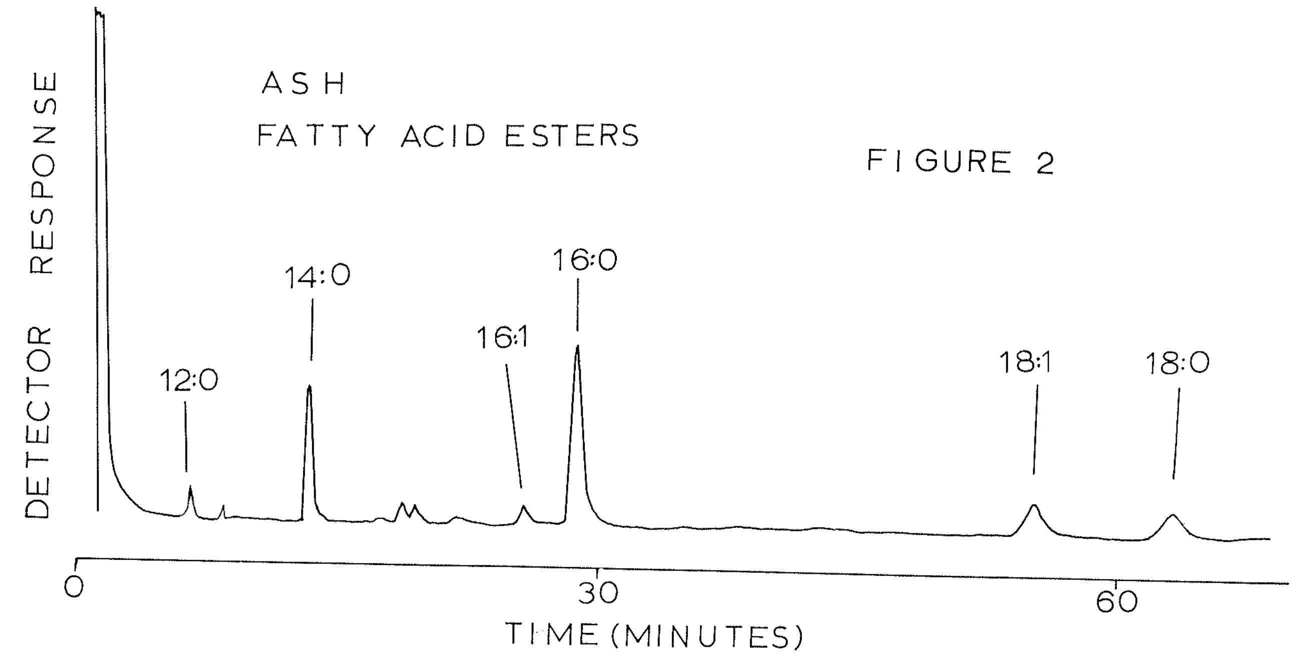


Fig. 2. Gas chromatogram of fatty acid methyl esters from ash. Copper column (8 feet × 1/8 inches o.d.) packed with 5% FFAP on Varaport 30. Barber Coleman (Series 5000) gas chromatograph with helium flow of 35 ml/min. Temperature programmed from 150°C to 225°C at 3°C/min.

TABLE I
ASH HYDROCARBON ANALYSES
SAMPLE I

Hydrocarbon	*Percent Composition*
n-16	trace
pristane	1.8
n-17	2.3
phytane	2.1
n-18	26.9
n-19	6.9
n-20	10.2
n-21	10.9
n-22	13.4
n-23	12.8
others	12.8

TABLE II
ASH SAMPLE I
FATTY ACID ANALYSES

Fatty Acid Methyl Ester	*Percent Composition*
12:0	trace
14:0	18.8
16:1	6.4
16:0	40.2
18:1	16.9
18:0	15.0
others	2.7

ACKNOWLEDGEMENT

The support of the NASA Sustaining Grant to Rice University and the NASA Summer Institute on Surtsey and Iceland is gratefully acknowledged.

References:

Abelson P. H. and Parker P. L. (1962): Fatty acids in sedimentary rocks. Annual Report Director Geophysical Lab. Carnegie Insitute Year Book 61, 181–184.

Blumer M. and Cooper W. J. (1967): Isoprenoid acids in recent sediments. Science 158, 1463–1464.

Cooper J. E. (1962): Fatty acids in recent and ancient sediments and petroleum reservoir waters. Nature 193, 744–746.

Haug P. (1971): Organic geochemistry of Iceland's extreme environments. NASA Technical Memorandum, NASA TM X-62, 009, Ames Research Center, 71–74.

Hilditch T. P. and Williams P. N. (1964): The Chemical Constitution of Natural Fats. Chapman and Hall, London.

Johns R. B., Belsky T., McCarthy E. D., Burlingame A. L., Haug P., Schnoes H. K., Richter W., and Calvin M. (1966): The organic geochemistry of ancient sediments — Part II. Geochim. et Cosmochim. Acta 30, 1191–1222.

Meinschein W. G. (1969): Hydrocarbons-saturated, unsaturated and aromatic. In Organic Geochemistry (editors G. Eglinton and M. T. Murphy), pp. 330–356, Springer-Verlag.

Moore C. B. (1971): Environmental relationship to the chemistry of thermal waters. NASA Technical Memorandum, NASA TM X-62, 009, Ames Reserach Center, 80–83.

Ponnamperuma C., Young R. S., and Caren L. D. (May 1967): Some chemical and microbiological studies of Surtsey. Surtsey Research Progress Report III, 70–80.

Ponnamperuma C. (1971): Personal communication.

Robinson W. E., Cummins J. J., and Dinneen (1965) Changes in Green River Oil-shale paraffins with depth. Geochim. Cosmochim. Acta 29, 249–258.

ODDI HF.